Handbook on the

STORAGE OF FRUITS AND VEGETABLES

for Farm and Commercial use

CANADA DEPARTMENT OF AGRICULTURE PUBLICATION 1260 1967

Publication 1260 1967

HANDBOOK ON THE STORAGE OF FRUITS AND VEGETABLES FOR FARM AND COMMERCIAL USE

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CANADA DEPARTMENT OF AGRICULTURE

QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1967

Cat. No.: A53-1260

PREFACE

The need for a convenient reference book on fruit and vegetable storage practices has been shown by the large number of requests from extension workers, fieldmen and others for information on this subject. The Farm Building Plan Service, which supplies information on storage construction, has also received many requests for instructions on the operation of storages.

This handbook has been published, therefore, to provide information for storage operators generally and to serve as a supplement to the plans and specifications supplied by the Canadian Farm Building Plan Service. It consists of general biological and engineering information, specific recommendations for the storage of fruit and vegetable crops, and a list of references to further detailed information.

Canadian fruits and vegetables are grown in areas that differ greatly in temperature, rainfall, hours of sunshine, and crop yields. For these reasons crops require somewhat different storage and handling in different areas and at different seasons. Similarly, methods of handling a crop vary according to the availability of labor, size of storage units, management policies, and so on. This handbook attempts to supply information that is applicable under all or most conditions.

People engaged in research on the storage of fruits and vegetables are continually improving storing procedures and equipment, such as devices for handling produce, structural and insulating materials, and equipment for controlled-atmosphere storage. Discoveries are also constantly being made in biological controls such as ripening inhibitors, chemicals for reducing disorders and methods of sprout control. Therefore, if this handbook is to be kept a reliable source of information, revisions will be required from time to time. Storage operators who do not find the answer to a particular problem are requested to write to the Food Research Institute, Canada Department of Agriculture, Ottawa, Ontario, so that suitable material may be included in future editions.

Caution must be exercised in using the chemical treatments suggested in this handbook as means of improving the storage characteristics of some fruits and vegetables. It is important to ensure that legal regulations, which may limit their use in a particular country or region, are strictly observed. These regulations are designed to protect the health and well-being of consumers. Essentially, the regulations pertain to residual amounts of chemical left in or on a product by a treatment. In Canada, before using a treatment, consult the Food and Drug Directorate, Department of National Health and Welfare, Ottawa, Ontario, or one of its regional directors or inspectors, to obtain current regulations.

ACKNOWLEDGMENTS

This handbook is made up of contributions from many workers in the Canada Department of Agriculture and elsewhere. The editors wish to acknowledge particularly the assistance of Professor E. W. Franklin, Ontario Agricultural College, University of Guelph, who not only submitted material for inclusion but also made constructive comments on the manuscript at various stages of its preparation; and the valuable contributions of Mr. G. L. Calver, Provincial Department of Agriculture, Victoria, British Columbia, Mr. L. G. Jorgenson, Provincial Horticultural Station, Brooks, Alberta, Dr. S. W. Porritt, Research Station, Summerland, B.C., and Dr. J. H. L. Truscott, Horticultural Products Laboratory, Vineland Station, Ontario.

The information in the handbook is based on first-hand observations of procedures and personal contacts with storage operators. This was made possible through the assistance of several agricultural engineers representing the Canadian Farm Building Plan Service in different parts of Canada.

Agriculture Handbook Number 66 of the United States Department of Agriculture, long regarded in both the United States and Canada as a particularly useful reference on storage operations, has been used extensively as a source book.

CONTENTS

PART 1 — GENERAL

THE STORAGE ENVIRONMENT

The function of a fruit or vegetable storage unit is to provide an environment that will permit produce to be stored as long as possible without losing quality — quality being a composite of flavor, texture, moisture content and other factors associated with edibility. The desired environment can be obtained mainly by controlling the temperature, composition and circulation of the storage atmosphere. The prevention of microbial contamination through sanitation is also important.

Maintenance of a suitable environment is complicated by the fact that fruits and vegetables consist of living tissues; this means that they are continually generating heat as a result of tissue respiration. In general, it can be assumed that the lower the temperature the less the amount of heat given off, because the processes associated with life proceed more slowly as temperatures are reduced. However, reduction of temperature can be harmful, as indicated by the development of "low temperature disorders." Further, if produce is severely frozen, the tissues die, and if it is subsequently thawed and stored, decay sets in and the produce becomes worthless.

Other factors besides temperature also affect storage environment. Because stored fruits and vegetables are living, they consume oxygen and give off carbon dioxide and other volatiles into the storage atmosphere. In addition, they are continuously giving off moisture and, although the rate of moisture loss is generally decreased by adding to the moisture content of a storage atmosphere, excessive moisture may contribute to the growth of microorganisms and promote deterioration.

Temperature of Storage

Temperature control is the most important single factor in the operation of a storage. The most suitable temperature depends on the type of produce and frequently on its particular variety or its ultimate use. Specific recommendations for different fruits and vegetables are given in Parts 2 and 3 of this handbook.

Heat extraction is the method used to achieve a desired temperature reduction; for example, to lower the temperature from a 70° F harvest temperature to a 32° F storage temperature. Quantities of heat are measured in British thermal units (Btu). Equipment capable of extracting 12,000 Btu per hour is rated as having 1 ton refrigeration capacity. A frequently used rule-of-thumb is that 1 ton of refrigeration is required for each thousand bushels of storage capacity (36). However, refrigeration loads must be calculated for

each refrigeration unit and the conditions under which it is to operate. Refrigeration requirements would be increased about one-third if the temperature during harvest were 80° instead of 70° F.

The heat that must be removed comes from three main sources: heat leakage, field heat, and metabolic heat or heat of respiration.

Heat leakage, for purposes of calculating refrigeration loads, means heat leaking into a storage room from the outside. The higher the temperature differential between the inside and the outside of a storage room, the greater will be the amount of heat leaking inwards. Heat leakage is controlled mainly by insulating materials used in the structure of a building. All the other structural components such as plywood, sheathing, roofing materials and supporting members contribute to the overall insulation of the building. However, these contributions rarely exceed 15 percent of the total insulating effect and are likely to be 10 percent or less.

Field heat is generally the greatest portion of the total refrigeration load. It represents the heat that has to be removed from produce and containers in order to reduce their temperature to the desired holding temperature.

Heat of respiration is an extremely variable portion of the refrigeration load. Rate of respiration varies with the kind and variety of produce, the storage temperature, the conditions under which the produce was grown, and its stage of maturity at harvest. Approximate values for the rate of evolution of heat for various crops at 32°, 40° and 60° F are given in Table 6.

Heat of respiration is an important part of the total heat load in storages; it may also be the cause of local heating and rapid produce deterioration if air movement is inadequate. This can occur wherever a fruit or vegetable itself or a package or a method of storage prevents transfer of heat of respiration. Thus, sweet corn, or other vegetables in too large a pile, or even boxed apples packed too tightly in storage, pose heat exchange problems.

Temperature greatly affects the rate of respiration and must be given special attention in any calculation of the heat produced in respiration. The refrigeration load due to the heat of respiration changes when a storage is being filled and cooled.

There are other heat sources, such as electric motors, lights, fans and workmen. These, along with loss in equipment efficiency, are usually taken care of in actual calculations by a "safety-factor" allowance. When storages are being planned, design engineers are needed to prescribe adequate building designs and adequate cooling equipment. However, prospective owners or operators must provide sufficient information about the intended operation to permit the total refrigeration load to be calculated (11, 36, 75). A sample calculation of refrigeration load is given in the Appendix.

Precooling

From the point of view of temperature control, storage has two phases: cooling and holding. Much more work must be performed by refrigeration equipment during the former than during the latter phase. Refrigeration during the holding phase is required only to remove heat leakage and heat of respiration and, normally, these are at fairly low levels after produce has been cooled.

Thus, if produce is to be cooled rapidly and efficiently, special equipment of high capacity is required.

Removal of produce heat by the use of chilled water (hydrocooling) is common for sweet corn and for leafy vegetables (49, 71). Air-blast coolers are used for many products, primarily before shipping (105). Shaved or crushed ice is also frequently blown in on top of produce before shipment, and is especially effective for fruits or vegetables likely to dry out during transit (3). Vacuum-cooling, now being used for lettuce and other leafy crops, cools a commodity by evaporating a small percentage of its own water content. This system of precooling is extremely fast and actually conserves freshness without the use of additional water (3).

Humidity of Storage

The humidity recommendations throughout this handbook are expressed in terms of relative humidity. The term "relative" humidity means the actual amount (or percentage) of moisture in the atmosphere at a given time as related to the maximum amount (100 percent) that could be retained at that temperature. Relative humidity values are affected by changes in temperature. For example, if air has a relative humidity of 80 percent at 40° F it will fall below 80 percent if the temperature is raised, and will rise above 80 percent if the temperature is lowered. If the temperature is lowered sufficiently, the relative humidity will reach 100 percent, representing a saturated condition. The temperature at which the atmosphere becomes saturated is referred to as the "dew point." This is the temperature at which dew or moisture forms, and the operation of a storage at or below this temperature results in the formation of wet spots from moisture condensation.

Maintaining the proper relative humidity is of great importance. If it is lower than optimum, produce will lose moisture by evaporation, and will wilt or shrivel. The amount of moisture loss depends on the type of produce, its structure, the ratio of surface area to volume, and the distribution of moisture inside it. On the other hand, depending on the amount of variation in temperature within a storage, very high relative humidities may result in the deposition of moisture on produce and on other surfaces. Such wet spots promote the growth of mold and rot organisms. Staining, particularly in onions, softening, and even splitting of skin are other detrimental effects attributed to high humidity.

The best way to maintain high humidity in a storage room is to install a cooling coil of sufficient capacity. The coil should be capable of absorbing the heat load when operated with a surface temperature of not more than 4° to 6° F below the temperature of the room's atmosphere. Undersized cooling coils, which must be operated with a low surface temperature, continually condense moisture, or frost, from the storage atmosphere. This lowers the humidity and results in abnormal moisture loss from produce. Watering the floor and the surface of containers or installing humidifying equipment are also helpful in keeping humidity high. Maintenance of uniform humidity requires adequate insulation of the storage room, proper stacking for air circulation, and close control of temperature.

In general, it is much more difficult to keep relative humidity at high than at low levels. However, jacketed storage rooms, until now used only in freezers, have proved effective in maintaining high humidities and reducing moisture loss from stored produce (55, 72).

The accurate measurement of humidity is somewhat difficult, particularly the measurement of high humidities at low temperatures. Sling psychrometers and other devices that operate on the wet and dry bulb thermometer principle are often used. Care in the use of such instruments is necessary if accurate readings are to be made. A more satisfactory but somewhat more costly method is based on the determination of dew points by electrical resistance.

Sweating

When cold produce is exposed to a warm atmosphere it usually becomes moist or even wet. This is referred to as sweating. It is caused by warm air losing moisture on contact with cold produce. Technically, it is brought about by the air temperature falling below its dew point. For example, air at 70° F and 75 percent relative humidity has a dew point of 63° F. In this atmosphere, produce would have to be at or above 63° F to avoid sweating. Produce at different temperatures below 63° F would show varying amounts of sweating. However, the dew point is seldom above 55° F, except in extremely humid weather.

The most effective way to avoid sweating when produce is removed from storage is to warm it gradually in storage to a temperature at or above the dew point of the atmosphere to which it will be transferred. If this is impractical and the produce must be removed during humid weather, it should be marketed quickly so that it is consumed before decay sets in.

Low-temperature Injury

There are two main causes of low-temperature injury: freezing and chilling. Freezing injury occurs when fruit or vegetable tissues have been cooled below the freezing point, which varies from about 27° to 30° F. Some commodities, like tomatoes, are damaged by slight freezing, whereas others, like parsnips, may be quite severely frozen without damage. If it can be avoided, no fruit or vegetable should be allowed to freeze. Even when no apparent damage is done, produce may depreciate faster in storage. Freezing injury is sometimes difficult to detect after thawing but the usual symptoms are some degree of brown discoloration with breakdown of tissues and a translucent or water-soaked appearance. Rough handling while produce is frozen usually increases the extent of freezing injury.

Chilling injury, on the other hand, is caused by metabolic disturbances resulting from low temperatures above the freezing point of the tissues. The control of chilling injury is one of the primary factors on which storage temperature recommendations are based. Symptoms of chilling injury are extremely variable. They include, for example, deep scald or breakdown in some varieties of apples, pigmentation complications in tomatoes, browning disorders or excessive sugar accumulation in potatoes, pitting of the skin of beans, susceptibility to fungal disorders in sweet peppers (18, 37, 67, 86, 87, 89).

Chemical Injury

Produce in storage may be damaged from contact with chemicals, especially with the more volatile ones. A refrigerant leaking from an evaporator or from pipes in a storage room is one cause of chemical injury. Ammonia is a frequent offender, damaging the skin of fruits and vegetables, particularly near lenticels (pores) or other openings. Injuries may be caused by ozone, sulphur dioxide, formalin and by-products such as ethylene, alcohols and aldehydes given off by other produce in storage. Control is best achieved through preventive measures, for example by elimination of refrigerant leaks, ample aeration after the use of disinfectants, and careful selection of produce when different kinds are stored together.

Waxing

A waxed coating applied to fresh fruits and vegetables has the prime function of preventing loss of moisture. Wax is usually applied after produce is removed from storage and before it is marketed. There are two recognized waxing procedures. One is the hot wax method in which fruits and vegetables are dipped briefly in almost pure paraffin wax held at about 260° F. In the second method, cold emulsions of various formulations are sprayed, brushed or foamed on or over produce. The hot wax method is restricted almost entirely to turnips, and sometimes parsnips, whereas emulsions are commonly used for citrus fruits, cucumbers and tomatoes. When using the hot wax method, be particularly careful to avoid damaging produce (33). Follow manufacturers' directions carefully when applying emulsions.

Storage Containers

There are a great many types of storage containers. Produce is often stored in the same container used for shipping and marketing, but recently special containers have been designed that are more satisfactory for storage. Also, it has been found advantageous to grade and pack fruits and vegetables throughout the storage season as they are required. This allows produce to remain undisturbed in storage for the maximum length of time and permits removal of diseased or damaged material just before marketing. However, when material coming from harvest contains a large amount of low-grade produce, it should be graded immediately to prevent valuable storage space being occupied with unmarketable or low-quality produce and to eliminate sources of spoilage.

Thus, much produce is held in special "bulk-bin" storage containers, which are constructed to last for several years. They are often used to carry produce from a growing area to storage with a minimum of damage. In storage, they must have good heat transfer characteristics, protect the produce and be suitable for stowage and handling. The most common size of bulk-bin container used throughout Canada for apples, potatoes and other crops holds about 1,000 pounds. It can be filled directly in the field and moved by tractor trailers and fork lifts. In rate of cooling and protection of produce against damage, the bulk bin compares favorably with the box or crate (60).

Nevertheless, crates or boxes that can be stowed by hand are still widely used. Their handling is facilitated by the use of pallets and mechanical lifting devices, which permit as many as 24 or more boxes to be moved and stacked as a unit.

Regardless of container type, openings must be left for air movement and heat exchange. When stowing, spaces should be left between the containers, the walls and the floor of a storage room, and also between the stacks of containers. It is also important to allow ample overhead space for free air movement from duct openings. (11, 60, 97)

Sanitation in Storage Rooms

Rot and mold organisms are sometimes a problem in storage rooms. They cause deterioration of containers and wooden structural materials, and also objectionable odors which may taint stored produce. It is very difficult to eliminate the organisms completely, but sanitary measures will reduce deterioration that otherwise might get out of control.

Any accumulation of damaged or decayed produce during storage and any partially filled boxes should be removed promptly. The most effective sanitary measure is thorough cleaning of a storage room as soon as it is empty, and well in advance of the following loading date. This cleaning can be done by using a detergent such as a 1 percent solution of tri-sodium phosphate followed by a spray of sodium or calcium hypochlorite solution containing 0.8 percent available chlorine (30).

After the room is cleaned, added protection can be obtained by use of fungicidal paints. The fungicidal ingredient remains active for some time after application (48). A common practice in potato storages is to spray the inside surfaces with 2-4-10 Bordeaux mixture (2 pounds copper sulphate, 4 pounds hydrated lime and 10 gallons water) (64). When washing or spraying the interior with any spray material, be careful to protect all electrical equipment. This applies to all metal structures as well, if corrosive material is used. Keeping storage rooms well ventilated and at a high temperature when not in use also helps to restrict the growth of molds.

Controlled Atmosphere Storage

Controlled atmosphere (CA) storage was investigated in Canada as early as 1933 but it was not used extensively until about 1953. It has since become an established procedure for apple storage. The main reason for its success is that it controls brown core, a very serious disorder in McIntosh apples, one of the most widely grown varieties in Canada. It has been used for pears and other crops to a limited extent, and there is little doubt that eventually it will be used for many more crops.

The CA storage room consists of a refrigerated chamber in which the concentration of carbon dioxide is held at a higher level and that of oxygen at a lower level than normally found in air. The room is made air-tight, or nearly so, by lining its walls and ceiling with metal, asphalt compounds, plywood, plastics or other materials. The room also has to be equipped with an air inlet for oxygen and a device (called a carbon dioxide scrubber) for

removing excess carbon dioxide. Detailed information about the construction and operation of CA storage units is available in various publications (15, 75, 96).

The original type of scrubber unit used sodium hydroxide in the water defrost device in its cooling unit. It has since been found that water is an effective absorbent for carbon dioxide when there is a large difference between the carbon dioxide concentration in the room and in the outside air. Thus, water scrubbers are now widely used, although caustic soda may be required initially until the desired level of oxygen is reached (11). In another system which is becoming quite popular, air is circulated through a "dry scrubber," a box containing bags of hydrated lime (calcium hydroxide). This scrubber has a minimum of mechanical devices, thus eliminating corrosion problems (17). In British Columbia, fans controlled by time clocks are used to circulate the air through dry scrubbers.

Shriveling because of moisture loss may be a problem in a CA storage when apples are kept there for an extended period. Consequently, special attention should be given to maintaining high relative humidity. For example, boxes or bins should be wet when the room is filled, and the floor should be kept slightly flooded with water during the entire storage period. As explained under "Humidity in Storage," the temperature of the cooling coil should be adjusted as closely as possible to that of the storage air. As already noted, a jacket-type storage is particularly useful for maintaining high relative humidity.

A CA storage requires a particularly effective moisture vapor barrier on

Table 1. — Controlled Atmosphere Storage Requirements for Some Varieties of Apples(a)

Variety	Carbon Dioxide (%)	Oxygen (%)	Temperature (°F)
McIntosh	5(b)	3	35 to 38(c)
Delicious	2 to 3	2.5 to 3	30 to 32
Golden Delicious	2 to 3	3	32
Rome Beauty	2 to 3	3	32
Northern Spy 1	5	3	35
Northern Spy 2	2	3	32
Stayman Winesap	5	3	32
Spartan	2 to 3	2.5 to 3	30
Newton	3	3	35
Jonathan	3 to 5	3	32
Baldwin	2 to 3	3	32
Macoun	5	3	38

(a) Various sources (See references 15, 96 and 99 in particular).

(b) 2 percent carbon dioxide for first month suggested in British Columbia.

(c) 38°F generally regarded as satisfactory; 35°F has been found better in British Columbia.

the outside of the insulation; otherwise, water vapor diffusing into the wall cavity is trapped by the air-tight lining of the room, resulting in a lowered insulation value and possible rotting of structural members. The jacket type of storage eliminates the problem of trapped moisture (56, 72).

Different varieties of apples often require different conditions of temperature and atmosphere composition in a CA storage. A summary of recommended conditions is given in Table 1. If carbon dioxide concentration reaches too high a level, external injury or internal brown-heart may develop. Likewise, if the oxygen concentration becomes too low, internal disorders that cause tissue breakdown accompanied by objectionable alcoholic flavors develop. (18, 50, 75, 78, 99)

Commodity Compatibility

The storage conditions for particular fruits and vegetables recommended on the following pages have been found optimal and also practical. They have been calculated to provide a margin of safety. However, when different kinds of produce are stored together the conditions described may need some modification.

Limitations are most commonly encountered because certain crops produce volatile substances that affect other crops. Apples give off ethylene and other volatiles, which can initiate sprouting in potatoes and cause tainting in other commodities, especially in dairy products. These effects are more pronounced at high temperatures. Thus, apples should not be stored with carrots, celery, cabbage, potatoes or onions. Similarly, celery and onions should not be stored together. Potatoes sometimes impart an earthy flavor to fruits, particularly at higher temperatures. Generally, dairy products should not be stored with fruits and vegetables.

Often, two commodities to be stored together have different temperature requirements. If so, it is safer to adjust the storage conditions to those of the commodity requiring the higher temperature. The reason for this is that when a storage temperature higher than 32° F is recommended, it is usually to avoid low-temperature injury. By storing at the higher temperature, this type of injury is avoided and the only loss is that the storage life of the low-temperature product will be shortened.

PART 2 — FRUITS

Recommendations for storing most Canadian-grown fruits are given in Table 2 and on the following pages.

Table 2. — Storage Life Expectancies, Recommended Storage Temperatures and Relative Humidities, and the Highest Freezing Points of Fresh Fruits

Fruit	Temperature (°F)	Relative humidity (%)	Approximate length of storage period	Highest freezing point(b) (°F)
Apples	Mostly 30 to 32(c)	85 to 95	as per variety and method of storage	28.9
Apricots	31 to 32	85 to 90	1 to 2 weeks	30.1
Blackberries	same as Raspberries			30.5
Cherries,				
sweet	31 to 32	85 to 90	10 days to 2 weeks	28.8
sour	31 to 32	85 to 90	few days	29.0
Cranberries	36 to 40	80 to 85	3 months	30.4
Grapes (American)	31 to 32	85 to 90	4 weeks	29.7
Peaches	31 to 32	85 to 90	2 weeks	30.3
Pears,				
Bartlett	30 to 31	85 to 90	2 to 3 months	28.6
fall and winter varieties	30 to 31	85 to 90	See variety list in text	29.2
Plums, including prunes	31 to 32	85 to 90	Prunes 4 to 6 weeks Plums see text	29.7
Raspberries	31 to 32	85 to 90	few days	30.0
Strawberries	31 to 32	85 to 90	5 to 10 days	30.6

(a) Based largely on Reference 115.
(b) Figures are from Reference 112. Maximum freezing points are given to indicate low-temperature safety limits.
(c) See also Table 1 on Controlled Atmosphere Storage.

Apples

Temperature: 30° to 32° F for most varieties.
Relative humidity: 85 to 95 percent.
For controlled atmosphere storage conditions, see pages 12 to 14.

Because apples benefit greatly from a good storage environment and because they are our most important fruit crop, more highly specialized

storage methods have been developed in Canada for apples than for other fruits. Studies by scientists and refrigeration engineers have produced a great deal of information on the storage of apples, and any storage operator will find much of this information helpful either directly or indirectly.

Apples direct from the orchard should be classified according to their storage potential before they are placed in storage. Poorer-keeping fruits should be placed in an accessible spot where they can be observed and marketed early; some may be directed to CA storage, and others placed in conventional storage according to a predetermined plan. From time to time during the storage period, to check estimates of storage behavior, small samples should be removed and allowed to ripen. The estimates made before storage are based on the variety and maturity of the apples, on cultural factors such as fertilizer application, weather conditions, spraying and pruning, and on an intimate knowledge of the orchards producing the apples.

The importance of variety is indicated in Table 3. As this table shows, variation in storage life is from a few weeks to seven months or longer, and some varieties are more susceptible to storage disorders than others.

Maturity at harvest has a pronounced effect on storage life. If apples are harvested in an immature condition, scald and browning disorders are induced in storage, whereas overmaturity hastens disorders associated with senility, such as some types of breakdown, mealiness and fungal rots (7, 18, 25, 30, 91). Unfortunately there is no completely satisfactory way to estimate maturity. Firmness, as measured by pressure testers of different types, is used extensively, but allowances must be made for irrelevant factors that can affect the readings. Starch content of apple tissue, measured by the iodine test, if properly performed, has been found a satisfactory maturity indicator for McIntosh. Immaturity is indicated by an abundance of starch; as apples mature their starch content decreases. Heavy dropping of apples occurs when the starch has almost disappeared (76, 80). This method may also be used, with modifications, for other varieties (30). Color charts that give a measure of changes in the ground color of apple skins are useful, and sometimes color changes in the flesh of some varieties are helpful (30, 57, 75, 99). Ease of separation from the tree and the number of days from full bloom are also good indications of maturity in some areas (30). The amount of red color or blush in "red" varieties is another criterion of maturity, and this has further significance because of grade regulations. Calendar date is often a good indicator although, depending on the area and the variety, harvest dates vary from year to year from several days to as much as three weeks. Nevertheless, in may areas, when used in conjunction with judgment based on experience, calendar date is a useful guide.

Fertilizer application and the nutrition of orchards influence storage behavior. Starvation of a particular element is usually very harmful. The nutrient having the greatest effect is nitrogen. High nitrogen levels tend to produce large, poorly-colored apples that are susceptible to scald and browning disorders (19). A good way to determine nitrogen effect is to make foliage analyses during the third week in July; depending on the variety, the presence of more than 2.0 to 2.3 percent of nitrogen (dry-weight basis) will probably reduce the quality and storage life of apples. Phosphorus appears to have little

Table 3. — Normal and Maximum Storage Periods for Some Common Apple Varieties and their Susceptibility to Storage Disorders(a)

Variety	Storage period Normal Months	Storage period Maximum Months	Tendency to storage scald	Other disorders likely to occur in storage
Gravenstein	0 to 1	3	Slight	Bitter pit, Jonathan spot.
Wealthy	0 to 1	3	Slight	Soft scald, Jonathan spot.
Grimes Golden	2 to 3	4	Severe	Soggy breakdown, bitter pit, shriveling.
Jonathan	2 to 3	4	Slight	Jonathan spot, water core, soft scald, internal breakdown.
McIntosh	2 to 4	4 to 5	Slight	Brown core, soft scald.
Cortland	3 to 4	5	Medium	Breakdown.
Rhode Island Greening	3 to 4	6	Severe	Bitter pit, internal breakdown.
Golden Delicious	3 to 4	6	Very slight	Shriveling, soggy breakdown.
Delicious	3 to 4	6	Slight to medium	Bitter pit, water core, internal breakdown.
Stayman Winesap	4 to 5	5 to 6	Severe	Internal breakdown, water core.
York Imperial	4 to 5	5 to 6	Severe	Bitter pit.
Northern Spy	4 to 5	6	Slight	Bitter pit.
Rome Beauty	4 to 5	6 to 7	Slight	Bitter pit, brown core, soft scald, internal breakdown, Jonathan spot.
Yellow Newton	5 to 6	8	Slight	Bitter pit, internal browning.
Winesap	5 to 7	8	Medium	Water core, shriveling.

(a) Based on Reference 115 with modifications from Canadian experience.

effect, and potassium content is significant only in offsetting the effect of a high nitrogen concentration. Thus, the greater the ratio of nitrogen to potassium the poorer the storage quality that can be expected (43).

Moderately cool weather with low rainfall tends to favor good storage quality. If the weather is too cold and wet, however, maturity tends to be delayed, and quality suffers in consequence. Extremely warm weather, on the other hand, hastens maturity and causes an increase in disorders. Warm, dry weather causes an increase in scald (21, 110), and induces water core in susceptible varieties (23, 99). The Jonathan variety should be harvested as soon as or before water core develops (30). Delicious apples with water core can be separated from good apples in an alcohol solution of approximately

0.877 specific gravity (83). Slight water core tends to disappear in storage but severe water core usually leads to tissue breakdown.

The use of hormone or "stop drop" sprays affects storage behavior by keeping mature apples on trees. Any factor that delays harvest tends to result in apples of more advanced maturity going into storage. Pruning also has an effect by disturbing the growing characteristics of trees; by allowing more light to fall on apples while they are growing, pruning usually results in increased fruit color.

If all the foregoing points are considered by a storage operator, he should be in a good position to assess the storage potential of his apple crop. In general, the apple with the highest storage potential is the one that is well colored, firm and of medium size.

The temperature at which apples are stored is important (77). For most varieties the storage temperature should be reduced to 30° F as rapidly as possible and held there throughout the storage period. It has been shown that as much as a 20-percent increase in quality retention can be achieved by keeping the temperature at 30° F instead of 32° F (77). However, temperature variation within a storage room must also be considered. If any part of the room is below the freezing point of the apples (29° F is the lowest safe temperature) then a higher operating temperature should be selected. Certain varieties are subject to low-temperature disorders, such as soggy breakdown and soft scald, and should not be stored below 34° to 36° F. These susceptible varieties include Jonathan, North Western Greening, Grimes Golden, Wealthy, Golden Delicious, Cox Orange and Winter Banana (18, 30, 91).

Humidity must be carefully controlled. The practical objective is to have high humidities without producing free water or drip. Humidity control depends largely on storage design and operation. With uniform temperature control, 95 percent relative humidity or higher can be maintained without difficulty. McIntosh apples held in commercial storages under these conditions have shown good quality retention and no harmful effects (72).

Careful handling at all times is extremely important; bruising predisposes apples to breakdown and rots. Freezing in the orchard may also affect storage behavior. Often night temperatures go below the freezing point of apples while they are on the tree. When this happens apples must not be handled while frozen, as they are extremely sensitive to damage at this time. If only lightly frozen, and if allowed to thaw before being picked, very little or no harm will occur. However, apples usually do not recover from severe freezing.

Superficial scald is probably the most serious storage disorder, particularly since the advent of CA storage. Formerly, this disorder was controlled by using shredded, oiled papers or oiled paper wraps. Recently, chemical dips have been used with greater effectiveness (39). Before using these compounds, refer to the legal regulations that apply to them in your area. If they are used, the manufacturer's directions should be followed exactly. Delayed harvest will reduce the development of scald. Well-colored apples are less likely to develop scald (30, 75, 98, 99).

Brown core (core browning or core flush) has been shown to be induced by various factors: immaturity, high nitrogen content, low temperature and senility. Therefore, it should be regarded as a symptom rather than a disorder.

Among the more common varieties, McIntosh is most susceptible to brown core. It can be controlled by CA storage but McIntosh apples held in conventional storage should be marketed before January. Gamma irradiation has been found experimentally to reduce both scald and brown core in McIntosh (70, 73).

Fungal wastage is the cause of considerable loss during storage (41). Fungal spores, which are almost always present on apples, germinate under suitable conditions, penetrate the skin and enter the flesh of the apples. As the storage season advances the fruit loses resistance to such invasions and the fungi make greater headway. The methods of control are: careful handling to avoid bruising or tearing the skin, sanitation to reduce the number of spores present, and avoidance of free water on the surface of apples as this tends to accelerate the growth and spread of organisms. Gloeosporium rot, a form of spoilage more common in the Maritimes than in other parts of Canada, appears to arise from orchard infections (20).

In addition to the more common disorders mentioned above, there are others, such as soft scald, soggy breakdown, Jonathan spot and lenticel spot, for which control measures and descriptions can be found in the literature (18, 91).

Further information on apples is given in References 7, 18, 30, 75, 97, 99 and 100.

Apricots

Temperature: 31° to 32° F.
Relative humidity: 85 to 90 percent.

Apricots are seldom stored for any length of time in commercial quantities and fruit picked sufficiently firm to ship or store, as well as fruit of normal canning maturity, does not have the same full flavor as tree-ripened fruit. Apricots suffer a continual loss of flavor in prolonged cold storage (115) but they keep well for 1 to 2 weeks at 31° to 32° F.

Cherries

Temperature: 31° to 32° F.
Relative humidity: 85 to 90 percent.

The approximate limit of storage life of sweet cherries is 10 days to 2 weeks. The storage life of sour cherries is much shorter, being a matter of a few days.

The black varieties (Bing, Lambert and Van) are usually harvested for shipping when they have reached a maroon color; for processing they are left on the tree until fully black. In many cherry-growing areas, the harvest maturity for sweet varieties, including the black and white types, is determined by a color chart (27). Rapid cooling immediately after harvest is important in that it preserves fresh appearance, prevents cracking of washed fruit, and reduces rate of browning of stems (stem color serves, on the market, as an indicator of quality) (27).

Cherries appear to be tolerant of fairly high levels of carbon dioxide (35) and high concentrations have been reported to extend their storage life.

Beneficial effects have been achieved by packing cherries in polyethylene bags, which permits the accumulation of 6 to 8 percent carbon dioxide.

At the end of their storage life cherries lose their fresh appearance, become dull, and frequently develop brown, gray, blue and green mold rots. Rotting is usually more critical when cherries are moved from storage in humid weather and accumulate moisture by sweating.

Cranberries

Temperature: 36° to 40° F.

Relative humidity: 80 to 85 percent.

A large part of the cranberry crop is held near to the bog or area where it is grown until Thanksgiving or Christmas market time. Because of this, cranberries may be held in common, air-cooled storages or in refrigerated warehouses. At a temperature of 36° to 40° F they can usually be held in storage up to 3 months, but fungal rots will develop after this period (115).

There is a high degree of variability in the storage characteristics of cranberries, which depend on the season, variety and maturity.

Poorly colored fruit continues to develop color if held at temperatures of 45° to 50° F. Precooling before long-distance shipment in warm weather reduces development of rots.

Grapes

Temperature: 31° to 32° F.

Relative humidity: 85 to 90 percent.

Most of the Canadian grape crop is of the Labrusca or American type which has a shorter storage life than the Vinifera or European type. American-type grapes are generally shipped direct to market for consumption or processing and they can be held up to 4 weeks if a temperature of 31° to 32° F is rigidly maintained. Hybrid varieties, such as Sheridan, can be stored successfully for periods up to 2 months. Sulphur dioxide fumigation is likely to damage the American type of grape but not the European type. Careless handling makes grapes crack and low humidity desiccates their stems. (40, 115)

Peaches

Temperature: 31° to 32° F.

Relative humidity: 85 to 90 percent.

Peaches require special handling for maximum storage life and retention of quality. Maturity is indicated by fruit filling out to a rounded shape from its somewhat flat-sided shape when immature. The pressure test is also a reliable indicator of maturity. If this test is used, harvesting should begin when pressure readings of 20 pounds or less are obtained with a 5/16-inch plunger; 19 to 14 pounds are regarded as optimal. The skin turns yellow when peaches are mature. The ideal maturity for harvest is reached when a peach becomes "eating ripe" in 6 to 8 days at 70° F. Overmaturity at harvest results in peaches having a stringy texture, whereas undermaturity causes peaches to have astringent flavors and a rubbery texture (101).

Postharvest conditions have a marked effect on the quality of peaches.

Cooling too quickly causes a mealy texture. It is best to hold peaches between 65° and 70° F for several days until they are nearly ripe, and then to cool them rapidly to 31° to 32° F. Peaches cooled in this way can be held for 2 weeks with good retention of quality, particularly of flavor. Unfortunately ripe peaches have to be handled very carefully. Because of this, an operator, facing the risk of ripe fruit being damaged in transit, sometimes sacrifices some quality by cooling and shipping partially ripened peaches.

Midseason varieties, such as Veteran, grown in the Okanagan Valley of British Columbia, when harvested firm-ripe will ripen normally if stored for not more than 2 weeks at 30° to 32° F. If held longer, they are liable to become mealy. Late varieties like J.H. Hale and Elberta will tolerate only 1 week at 30° F without developing a mealy texture when ripened. The mealiness appears to be caused by a disturbance of the pectin-hydrolyzing system at low temperatures and the effect seems to be cumulative, because exposure to low temperatures before harvest reduces the tolerance of fruit when placed in storage. Sometimes this mealiness or dryness is referred to as "wooliness."

The main causes of spoilage in peaches are brown rot and Rhyzopus rot. Orchard sprays and careful inspection of fruit entering storage can prevent these rots to some extent. Spread of the rots in infected peaches can also be controlled by immersing them in hot water at a temperature of 120° F for 30 minutes or 130° F for 3 minutes (58). Rhyzopus rot has been controlled during a 6-day ripening period by initially dipping fruit in Botran (2,6-dichloro-4-nitroaniline) at a concentration of 1.5 pounds per 100 gallons of water. (26, 28, 105)

Pears

Temperature: 30° to 31° F.
Relative humidity: 85 to 90 percent.

Although pears are related to apples genetically, storage and handling procedures for the two crops are different in many respects. Most varieties of pears are harvested in the hard green state but the rate of softening during harvest is more rapid than with apples. Thus, the pressure test is a more satisfactory maturity guide with pears than with apples and a relatively small plunger (5/16 inch instead of 7/16 inch) is suitable because of the firmer flesh of pears at harvest. Recommended pressure test readings and storage periods for pears are given in Table 4. Skin color is also a maturity guide but sometimes a difficult one to use because harvesting maturity is indicated by a loss of green pigment and a change from a darker to a lighter green. This loss of green pigment usually takes place in the skin areas between the lenticels, producing a mottled effect with the darker green color being retained around the lenticels.

If pears are harvested too early, they fail to ripen normally and are likely to wilt and shrivel in storage. If harvested when too mature, pears develop a gritty texture, and breakdown and other physiological disorders occur. Although it has been shown that Bartlett pears, for example, may increase as much as 20 percent in weight after reaching their recommended harvest maturity, this advantage may be offset by a shortened storage life.

Pears should be cooled as rapidly as possible after harvest (29). Rapid cooling is probably the most important single factor contributing to their satisfactory storage. For example, it has been found that breakdown in pears kept an equal number of days in storage is increased threefold when the pears are cooled from 65° to 30° F in 8 days instead of 4 days (82).

Pears, with few exceptions, begin to ripen when their skin becomes yellow, and if they are allowed to remain at low temperatures during this period they will break down and develop scald. Thus, it is extremely important to ripen pears at higher temperatures — 68° F is ideal (5). For a description of pear disorders, see Reference 29.

Table 4. — Recommended Pressure-Test Readings for Harvest, and Approximate Storage Life of Some Varieties of Pears(a)

Variety	Pressure test range (pounds with 5/16-inch plunger)	Storage life at 30°F (months)
Anjou	13.0 to 12.0	4½ to 6
Bartlett	20.0 to 18.0	2 to 3
Beurre Bosc	14.0 to 12.0	3 to 3½
Clairgeau	15.0 to 11.0	
Comice	13.0 to 9.0	2 to 3
Doyenne Boussock	14.0 to 12.0	2
Flemish Beauty	12.0 to 11.0	2
Hardy	11.5 to 9.0	2 to 3
Kieffer	16.0 to 12.0	2 to 3
Winter Nelis	14.0 to 12.0	4½ to 5

(a) Data obtained from References 1, 29, 38 and 115.

Bartlett — This variety is normally harvested in the latter part of August or early September. Harvesting operations should not start before the pressure test indicates 20 pounds; 19 pounds is better if the fruit can be harvested within a week after this point is reached. For calculation purposes, the rate of softening is usually about ¼ pound per day. It is extremely important that the pears be placed in storage or a precooler immediately so that the core temperature is reduced to 30° or 31° F as rapidly as possible (81, 82). This can be accomplished in 3 to 4 days with good facilities. Under such conditions the minimum storage life should be 60 days. The pears should be removed from storage early enough to ensure that they reach their destination before yellowing. Ripening should be carried out at 68° F with high humidity.

Fall and winter varieties — There may be 10 or more varieties of pears other than Bartlett grown in Canada. Collectively, however, these other varieties do not equal Bartlett in volume produced. Recommendations respecting firmness for harvesting, along with storage life expectancies, are given in Table 4. Pressure tests are somewhat less reliable indicators of maturity of fall and winter varieties as they do not soften on the tree as rapidly as Bartletts. Changes in skin color, particularly of Anjou pears, may be a more reliable maturity indicator than firmness. The same general storage and ripening pro-

cedures as outlined for Bartletts apply to these varieties. (2, 29, 31, 32, 38, 91, 106)

Pears are stored under CA conditions in some countries (51) and small-scale trials have been successful in Canada (106). However, full-scale commercial CA storage of pears is not practised in Canada.

Plums (including Prunes)

Temperature: 31° to 32° F.
Relative humidity: 85 to 90 percent.

Maturity of prunes at harvest has a pronounced effect on their subsequent ripened quality. The most reliable indicator of maturity is their soluble solids content, as indicated by refractive index. Harvested prunes having a 17 to 18 percent soluble solids content, by refractometer, will ripen in about 7 days at 65° F, and after storage for 1 month at 32° F they will ripen in 5 days at 65° F (24). Color may also be used as an indicator: prunes are considered ready for harvest when their flesh color reaches a medium-dark amber. The pressure test apparently gives results that are too variable from year to year to be reliable (24, 34).

Early plums (Japanese type) are susceptible to breakdown, which is increased by storage at 32° to 40° F. Thus, storage below 40° F is hazardous, but above this temperature storage life is relatively short. Other types of plums can be stored at 31° to 32° F and the storage life at these temperatures is 2 to 3 weeks or slightly longer, depending on variety and maturity at harvest.

The chief disorders of plums, other than fungal wastage, are internal browning and breakdown. These are not visible externally and so frequent internal examination is necessary to avoid holding this crop beyond its marketable limit (24, 34, 67, 115).

Raspberries

Temperature: 31° to 32° F.
Relative humidity: 85 to 90 percent.

Fresh raspberries, blackberries, Logan blackberries and dewberries are not adapted to storage and are not usually stored commercially. They can be held for 5 to 7 days at 31° to 32° F and a relative humidity of 85 to 90 percent. Young and Boysen dewberries cannot be held longer than 2 to 4 days (115).

Strawberries

Temperature: 31° to 32° F.
Relative humidity: 85 to 90 percent.

Fresh strawberries are not usually stored commercially but may be held for a maximum of 10 days at 31° to 32° F and 85 to 90 percent relative humidity. If the temperature rises above 40° F the growth of gray mold and *Phytophthora* (leather rot) is accelerated. In storage, strawberries are likely to lose flavor and brightness of color (115).

Precooling is essential before long shipment and is beneficial under other circumstances. This is usually accomplished by forced air cooling either before or after loading. Strawberries should be transported under refrigeration.

PART 3 — VEGETABLES

Recommendations for storing most Canadian-grown vegetables are given in Table 5 and on the following pages.

Table 5. — Storage Life Expectancies, Recommended Storage Temperatures and Relative Humidities, and the Highest Freezing Points of Fresh Vegetables

Vegetable	Temperature (°F)	Relative humidity (%)	Approximate length of storage period	Highest freezing point(b) (°F)
Asparagus	32	95	3 weeks	30.9
Beans,				
Green or snap	45 to 50	85 to 90	8 to 10 days	30.7
Lima,				
shelled	32	85 to 90	2 weeks	31.0
unshelled	32	85 to 90	2 weeks	30.9
Beets, bunched	32	90 to 95	10 to 14 days	31.3 (Tops)
Topped	32	90 to 95	1 to 3 months	30.3
Broccoli (Italian or sprouting)	32	90 to 95	1 week	30.9
Brussels sprouts	32	90 to 95	3 to 4 weeks	30.5
Cabbage,				
Early	32	90 to 95	3 to 4 weeks	30.4
Late	32	90 to 95	3 to 4 months	31.7
Carrots,				
Bunched	32 to 34	95	2 weeks	
Topped	32 to 34	95	4 to 5 months	29.5
Cauliflower	32	90 to 95	2 weeks	30.6
Celery	32	95+	3 months	31.6
Corn, sweet	32	90 to 95	8 days	30.9
Cucumbers	45 to 50	95	10 to 14 days	31.1
Eggplants	45 to 50	85 to 90	10 days	30.6
Endive or escarole	32	90 to 95	2 to 3 weeks	31.4
Garlic, dry	32	70 to 75	6 to 8 months	30.5
Horseradish	30 to 32	90 to 95	10 to 12 months	28.7
Kohlrabi	32	90 to 95	2 to 4 weeks	30.2
Leeks, green	32	90 to 95	1 to 3 months	30.7
Lettuce	32	95	Head lettuce 2 to 3 weeks	31.7
Melons, Cantaloupe or				
Muskmelon	32 and 45	85 to 90	2 weeks	30.5
Honey dew	45 to 50	85 to 90	2 to 3 weeks	30.1
Watermelons	36 to 40	85 to 90	2 to 3 weeks	31.3

Vegetable	Temperature (°F)	Relative humidity (%)	Approximate length of storage period	Highest freezing point(b) (°F)
Mushrooms, cultivated	32	85 to 90	5 days	30.4
Onion sets	32	70 to 75	5 to 7 months	
Onions, dry	32	50 to 70	5 to 9 months	30.4
Parsnips	32	95	2 to 4 months	30.4
Peas, green	32	95	1 to 2 weeks	29.9
Peppers, sweet	45 to 50	85 to 90	8 to 10 days	30.7
Potatoes,				
Early-crop	See text	85 to 90	1 to 3 weeks	30.3
Late-crop	See text	85 to 90	See text	30.3
Pumpkins	44 to 50	70 to 75	2 to 3 months	30.5
Radish,				
Spring, bunched	32	90 to 95	2 weeks	31.3
Winter	32	90 to 95	2 to 4 months	30.7
Rhubarb	32	90 to 95	2 to 3 weeks	30.3
Rutabaga or turnip	32	90 to 95	6 months	30.1
Salsify	32	90 to 95	2 to 4 months	30.4
Spinach	32	90 to 95	10 to 14 days	31.5
Squash,				
Summer	44 to 50	70 to 75	2 weeks	31.1
Winter	44 to 50	70 to 75	6 months	30.7
Sweet potatoes				30.1
Tomatoes				
Ripe	50	85 to 90	3 to 5 days	31.1
Mature green	55 to 60	85 to 90	2 to 6 weeks	30.5

(a) Based largely on Reference 115.

(b) Figures from Reference 112. Maximum freezing points are given to indicate low-temperature safety limits.

(c) See also Table 1 on Controlled Atmosphere Storage.

Asparagus

Temperature: 32° F.

Relative humidity: 95 percent.

Asparagus should be cooled to 32° F immediately after harvest and held at this temperature at very high humidities. Under these conditions it may be stored as long as 3 weeks. Because loss of moisture from the spears is difficult to control, the butts are often placed in water or in contact with damp moss or other sources of moisture. Temperatures higher than 32° F tend to promote growth, cause "loose heads," and hasten the onset of woodiness or toughness. Because of these storage difficulties asparagus is normally marketed directly after harvest and is placed in storage only as a temporary measure. If there is a long interval between harvesting and marketing, asparagus should not be held long at destination. Under such circumstances precooling before shipment is extremely important. Icing the product before storage or shipment is also beneficial. Two kinds of microbiological spoilage, bacterial soft rot and gray mold, can affect asparagus during storage. (54, 68, 108, 115)

Beans, Green or Snap

Temperature: 45° to 50° F.
Relative humidity: 85 to 90 percent.

Snap beans, if cooled immediately after harvest and held at 45° F, can be stored for 8 to 10 days. Contact icing of snap beans should be avoided. If held at temperatures of 40° F or lower they are subject to chilling injury, evident as pitting in storage and russeting after removal from storage. Air circulation is important at all times. If the air becomes stagnant, moisture accumulates at the center of the mass, hastening the onset of decay and other damage. The main forms of decay occurring in snap beans that are held too long are watery soft rot, slimy soft rot, Rhyzopus rot, gray mold rot and anthracnose. (115)

Beans, Lima

Temperature: 32° to 40° F in pods; 32° F shelled.
Relative humidity: 85 to 90 percent.

Lima beans, when stored in the pod, have a storage life of approximately 2 weeks at 32° F or 10 days at 40° F. Good air circulation is as important as it is for snap beans and the rot-type disorders are the same for both types of beans. Lima beans are often stored after shelling. If fresh, they can be held for about 2 weeks at 32° F or 4 days at 40° F. If they are held too long after shelling they become sticky and their color fades. (115)

Beets

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Beets are sold either with tops on or with tops removed. The former style is referred to as "bunch beets" and is primarily for the retail trade. The latter style is referred to as "topped beets" and is used for processing and, to some extent, for the retail trade. Bunch beets are often harvested before they reach full maturity (about 1½ inches to 3 inches diameter). They are not held in storage for long periods although they can be held for 10 days to 2 weeks at 32° F at a high relative humidity. Wilting and other damage to the tops can be lessened if beets are not crowded in storage. Sometimes the tops are lightly trimmed so that they do not look wilted. Icing before transportation to market helps maintain a fresh appearance and longer shelf life.

Topped beets are more mature, and are harvested in the fall before danger of freezing. Loose soil is removed and the beets are topped by cutting close to the crown. All damaged and misshapen beets should be discarded. Irregular or coarse roots are likely to be tough and woody; damaged beets are likely to shrivel or be a source of infection in storage. Because beets have a strong tendency to shrivel, a high relative humidity should be maintained during storage. Under these conditions, and at 32° F, beets may be held for 1 to 3 months. Root cellars and refrigerated storages are both satisfactory, and storage in ventilated barrels or slatted boxes is preferable to bulk storage. (69, 115)

Broccoli (Italian or Sprouting)

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

The storage life of broccoli is about 1 week under favorable conditions. After this the buds usually drop off and the whole head becomes discolored. For even this short storage life broccoli requires refrigeration during transit and in the retail market. Continuous icing or a steady temperature of 32° F is necessary to reduce wastage and loss of vitamin C. The most important types of spoilage are bacterial spot, bacterial soft rot, gray mold rot and watery soft rot. (85, 115)

Brussels Sprouts

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Brussels sprouts are a short-storage crop, but they can be held for periods of 3 to 4 weeks at 32° F at a high relative humidity. They should be stored in small containers to prevent yellowing and development of mold. They suffer from the same disorders as cabbage and the best control is effected by low storage temperatures with adequate air circulation. (115)

Cabbage

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Early cabbage, which is normally harvested during the summer, before the crop reaches full maturity, has a storage life of 3 to 4 weeks at 32° F and high relative humidity. Since this crop is usually grown for immediate sale, there is no great economic advantage in holding it for long periods in storage.

Late cabbage, or the solid Danish Ballhead type, has a storage life of 3 to 4 months if held at 32° F at a high relative humidity. Although high humidities are required to prevent wilting, good air circulation is also necessary to prevent excessive dampness within the pile. The late cabbage crop is harvested in the fall when it is fully mature, as shown by solid, heavy heads, and a heavy waxy bloom on all the leaves, which gives them a steel-blue color. After harvest the roots are trimmed fairly close to the base of the heads. Dead or damaged leaves are removed. At least one layer of healthy outer leaves should be retained to protect each head during handling and storage. Further trimming is usually needed when heads are removed from storage before marketing. The best storage is attained with shallow layers on top of slatted shelves but the heads can also be stored by piling to a depth of not over 5 feet if ample aeration, often by forced air, is provided within the pile or stack. The monetary value of this crop usually does not justify storage under refrigeration, hence cabbages are usually held in common, air-cooled storage. Freezing should be avoided if possible, but cabbage will recover from light freezing. The main disorders occuring in storage are caused by wilting, and by infections of *Rhyzopus* and other fungi. (85, 115)

Carrots

Temperature: 32° F.
Relative humidity: 95 percent.

For long storage carrots are harvested when mature and after the leaves have assumed a slightly browned appearance. Harvesting in cool, cloudy weather to prevent drying of the roots from the time they are dug until they are placed in storage, and maintaining the relative humidity in storage at 85 percent or higher, will reduce the browning disorders that often occur. During harvest, carrots are topped to retain the crown or top of the root, and objectionable roots are discarded. Coarse, damaged, distorted roots and the crease in the crown form focal points for subsequent decay. Properly matured carrots can be stored up to 10 feet deep in bins if aeration, preferably by forced air, is provided. It is customary, however, to store carrots in bulk bins, ventilated barrels or slatted crates. The monetary value of mature carrots does not usually justify storing under refrigeration. In common storage, most varieties may be held 4 to 5 months at 32° to 40° F. The longer-storing varieties include Chantenay, Danvers, Gold Pack, Imperator and Nantes. Such varieties as Touchon have a slightly shorter storage life of about 3 to 4 months. Adequate air movement helps to prevent bitter flavors caused by ethylene. Also, ethylene-producing fruits such as apples and pears should not be stored in the same area as carrots. High humidity is required to prevent shriveling or wilting, and, on a small scale, carrots can be stored in damp moss, coarse sawdust, layers of newspaper, sand or other materials that will control moisture loss (69).

More tender, immature carrots are harvested at less than 1½ inches in diameter for immediate consumption or short storage. They are sometimes sold as bunched carrots with tops retained, but the tops may remove moisture rapidly from the roots and they are prone to discoloration by yellowing. Therefore, even immature carrots are usually sold with tops removed. They may be packed in transparent film packages for the retail market or in crates for long-distance shipment. They should be hydrocooled down to 40° to 45° F or lower soon after harvest and before packing for shipment. If shipped open in crates they can be top-iced to retain their freshness. The storage life of young carrots varies from several days to 2 weeks, depending on their age and storage conditions.

Carrots in storage may be damaged by severe freezing, although they will recover from a light frost. They may also become shriveled through loss of moisture. Watery soft rot or bacterial soft rot may be prevalent towards the end of storage life. Discarding damaged or coarse roots at harvest helps control these disorders, as do ventilation and frequent inspection during the storage period. (115)

Cauliflower

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Cauliflower is not usually stored. If necessary, however, it can be held, at a high relative humidity, for about 2 weeks at 32° F or 1 week at 40° F,

provided the produce is placed in storage in good condition immediately after harvest. Cauliflower is usually packed in crates after being harvested and trimmed. It is best to place the heads downwards to avoid damage by contact with water, soil or other foreign matter. Spoilage of cauliflower in storage may occur through wilting or decay, or through white curds in the heads maturing and turning brown, or starting to grow so that they have a ricey appearance. These disorders are most effectively inhibited by low temperatures. Thus, the application of crushed ice or snow before transit, or in lieu of storage, is strongly recommended (115).

Tests in the United Kingdom have indicated that the storage life of cauliflower may be extended 2 weeks by the use of controlled atmosphere storage. The conditions suggested are 10 percent carbon dioxide, 11 percent oxygen and 79 percent nitrogen at a temperature of 32° to 34° F (95).

Celery

Temperature: 32° F.
Relative humidity: 95 percent.

Celery, if cooled rapidly after harvest and held at 32° F and high relative humidity, has a storage life of approximately 3 months. Because celery is extremely prone to wilting, rapid cooling after harvest is essential. Immersion in ice water and other forms of hydrocooling either before or after packing in crates have been found most satisfactory (71). Vacuum-cooling is also helpful, and top-icing is particularly beneficial before transit.

Freezing damage has been reported at temperatures as high as 31.5° F (56). However, temperatures below 34° F are needed to prevent the growth of rot organisms in storage. It is absolutely essential, therefore, that precise temperatures be maintained. Because of the leafy nature of the crop and its fairly high heat of respiration, special attention to stacking in storage rooms is necessary to maintain uniform temperatures. Spaces for air movement both vertically and horizontally are needed between crates and the celery should be trimmed flush with the top of the crates.

Some storage disorders such as soft rots, mineral deficiencies and root rot have their origin in the field. To prevent the development of these disorders it is helpful to have a knowledge of the conditions under which the celery was grown and to inspect celery going into storage. Root rot, caused by *Ansatospora macrospora* (Osterw.) Newhall, can be controlled by dipping the trimmed butts of celery in a 2-percent suspension of copper 8-quinolinolate (104). (*Important:* Before employing these chemicals, refer to the legal regulations that apply to their use in your area.) Most other storage disorders are caused by fungi and develop rapidly once established. Close scrutiny of celery during storage is advisable.

Tests on a semi-commercial scale have shown that jacketed storage provides a much improved method of storing celery (56).

For further information on celery, see References 113 and 115.

Corn, Sweet

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Sweet corn has a maximum storage life of 8 days if cooled and stored under optimum conditions. It should be harvested at the milk stage (when the juice from the kernel is milky in appearance) and cooled as rapidly as possible. Hydrocooling by spraying or immersion in water at temperatures near 32° F is most effective. Vacuum-cooling and air-cooling can also be used if corn is moist. The main purpose of cooling is to retain the original flavor and succulence of the corn. But these qualities are lost through normal reactions involving, in particular, the conversion of sugars to starch. Because these reactions proceed more rapidly at high temperatures (about five times as quickly at 80° F as at 32° F (4)), it is important to cool corn as quickly as possible (49).

When shipped to market, sweet corn should be copiously iced and care should be taken to have the ice in contact with as much of the corn as possible. Because the insulation afforded by the husk and the cob tends to withhold the heat of respiration, a certain amount of air circulation within the stack is also recommended. These conditions are most easily attained if corn is packed in crates, the 5-dozen size being most common.

Exposure to carbon dioxide at low temperatures has been shown to be effective in lessening sugar loss. However, if proper precautions are not exercised damage may occur (59).

Further information on sweet corn is given in Reference 46.

Cucumbers

Temperature: 45° to 50° F.
Relative humidity: 95 percent.

Cucumbers have a storage life of only 10 days to 2 weeks at 45° F and high relative humidity. They are quite sensitive to temperature: below 45° F chilling injury develops, as evinced by surface pitting and dark watery patches, and this is followed by the onset of rots, particularly when the temperature is raised. At temperatures above 50° F, on the other hand, yellowing occurs. Thus, it is quite important that cucumbers be cooled quickly to 45° to 50° F, and that they be held at this temperature during storage or transit. Slatted crates permit good air exchange and are recommended. Cucumbers are sometimes waxed to reduce moisture losses. (115)

Eggplant

Temperature: 45° to 50° F.
Relative humidity: 85 to 90 percent.

Eggplant cannot be expected to keep satisfactorily in storage for more than about 10 days. The optimum storage temperature is 50° F or slightly lower. Slight surface pitting and bronzing, especially near the stem, has been noted at temperatures of 40° F or lower in 4 to 8 days. The pits sometimes occur in groups and coalesce into larger sunken areas on longer exposure. (115)

Endive or Escarole

Temperature 32° F.
Relative humidity: 90 to 95 percent.

Endive or escarole is a leafy vegetable which, under commercial conditions, is not adapted to long storage. Even at 32° F, which is considered to be the best storage temperature, it cannot be expected to keep satisfactorily for more than 2 or 3 weeks. The storage requirements for endive are practically the same as for lettuce. As with lettuce, the use of cracked ice extends its storage life. The relative humidity should be kept at 90 to 95 percent to prevent wilting. A certain amount of desirable blanching usually occurs in endive that is held in storage. (115)

Garlic, Dry

Temperature: 32° F.
Relative humidity: 70 to 75 percent.

Garlic is best stored under the temperature and humidity conditions recommended for onions. It should be well cured before going into storage; then, if it is in good condition, it should keep at 32° F for 6 to 8 months. Sometimes garlic is stored in common, air-ventilated storages; under these conditions, if kept cool, dry and well ventilated, it may be held for 3 to 4 months, or sometimes longer depending on the temperature. Garlic is usually stored in loose mesh bags, which are piled two layers deep in stacks separated by air spaces. (115)

Horseradish

Temperature: 30° to 32° F.
Relative humidity: 90 to 95 percent.

Horseradish keeps satisfactorily for 10 to 12 months at 30° to 32° F and at 90 to 95 percent relative humidity. Roots dug when the plants are actively growing do not keep as well as roots that have been conditioned by cold weather before digging. Frequent inspection is advisable. (115)

Kohlrabi

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Kohlrabi should keep 2 to 4 weeks if stored at 32° F and 90 to 95 percent relative humidity. (115)

Leeks, Green

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Green leeks are packed in crates and stored under conditions similar to those suitable for celery. If properly handled, they should keep satisfactorily in storage for 1 to 3 months. (115)

Lettuce

Temperature: 32° F.
Relative humidity: 95 percent.

Although there are several types of lettuce, practically all commercial lettuce is of the crisp head type. Lettuce is not a long-storage crop but if its temperature is reduced rapidly to 32° F and held at this level while the humidity is kept very high, head lettuce can be stored for 2 to 3 weeks or possibly slightly longer.

Hydrocooling in ice water and icing in storage help to retain freshness and are most effective if done immediately after harvest and trimming. All damaged lettuce, particularly any affected with tip burn, should be discarded. This disorder leads to breakdown and to slimy rots in storage.

Vacuum-cooling has produced revolutionary changes in the handling of lettuce in specialized growing areas. Large quantities of lettuce in boxes or crates are placed in a chamber, which is then evacuated to cause evaporation of the water inside and adjacent to the lettuce, and to produce rapid cooling. Because containers remain dry when cooled in this manner, fiber containers may be used, and rots are reduced during transit and marketing. (84, 115)

Melons

There are three main types of melons sold in Canada: cantaloupe, honeydew and watermelon. The first two are botanical varieties of muskmelon. Melons as a whole do not have a long storage life. However, by cooling, spoilage is delayed during transit and marketing, and temporary storage is made possible during times of market surplus.

Cantaloupe or Muskmelon

Temperature: 32° and 45° F.
Relative humidity: 85 to 90 percent.

Cantaloupe normally has a storage life of approximately 2 weeks at 32° F but, under certain undetermined conditions, some varieties may suffer from low-temperature breakdown below 45° F. Maturity, which affects both storage behavior and market quality, is determined by stem separation and color. Optimum harvest maturity is at the stage of "full slip" when the stem separates completely and cleanly and before yellowing has occurred. Such melons do not have as long a storage life as less mature melons but they have the advantage of higher quality (62). More mature cantaloupes can be stored safely at lower temperatures. Icing is often used as a means of cooling these melons. Cantaloupe should be inspected often and very carefully in storage and on the market to detect spoilage before it reaches serious proportions. (115)

Honeydew

Temperature: 45° to 50°.
Relative humidity: 85 to 90 percent.

This melon has an expected storage life of 2 to 3 weeks at 45° F. Disorders are very similar to those of cantaloupe. It is considered somewhat hazardous to use ice for cooling melons other than cantaloupe. (115)

Watermelon

Temperature: 36° to 40° F.

Relative humidity: 85 to 90 percent.

Watermelon has a storage life of 2 to 3 weeks at 36° to 40° F. If held at 32° F pitting and objectionable flavors develop. The onset of decay is the factor that usually determines the end of storage life. (85, 115)

Mushrooms, Cultivated

Temperature: 32° F.

Relative humidity: 85 to 90 percent.

Fresh mushrooms do not keep well and are therefore stored only for short periods. Deterioration is marked by brown discoloration of surfaces and by opening of veils. Freshly picked mushrooms will keep in prime condition at 32° F for 5 days, at 40° F for 2 days and at 50° F for only 1 day. Allowing a marketing period of only 1 day at higher temperatures immediately after storage, they should be kept at 32° F for only 3 to 4 days and at 40° F for up to 2 days. When they are being transported and displayed for sale, mushrooms should be kept constantly under refrigeration. (115)

Onions

Three forms of onion are kept in storages: green (small bunched) onions, sets (small cured bulbs sold in the dry state for planting purposes), and dry onions (cured full-sized bulbs). The last is the principal type held in storage.

Green

Temperature: 32° to 45° F.

Relative humidity: 95 percent.

Onions in this form have a short storage life. Hydrocooling and icing can be employed to retain freshness. When treated in this manner green onions can be held up to 2 weeks.

Sets

Temperature: 32° F.

Relative humidity: 70 to 75 percent.

Onion sets are usually stored in common, air-cooled, storages. Because of their small size they are stored in shallow, slatted trays to provide ample air circulation. If piled to any depth, the onion sets tend to pack tightly, prohibiting air movement. Otherwise they require the same storage treatment as dry onions.

Dry or Cured

Temperature: 32° F.

Relative humidity: 60 to 70 percent.

Botanically the onion is a biennial; the first year it produces a bulb, the second year flowers and seeds. The object of storage is to prevent even the slightest form of growth within the bulb. The bulb, during early storage, is in the resting state and incapable of growth, but after 3 to 5 months it

changes from this state and enters a critical period in its storage life when both internal and external symptoms of growth may develop. Slight rises in temperature during this period hasten growth. Even the internal development of sprout growth reduces quality and eventually terminates storage life. Thus, the storage life of dry onions may be about 5 months, depending on variety, temperature control and other factors.

However, if treated before going into storage with sprout inhibitors such as maleic hydrazide or gamma irradiation, onions will remain in the resting stage indefinitely. Thus, their storage life may be extended to as long as 8 to 9 months, depending on such factors as the effectiveness of the sprout inhibitor treatment, the variety of the onions, the presence of disease and the curing procedure used. (*Important:* Refer to the legal regulations that apply to the use of sprout inhibitors in your area before employing them.)

Onions are harvested when mature, which is usually taken to be when at least 50 percent of the stems have bent down to the ground. They are dug and topped and may be left in the field for curing; brittleness of skin and contraction of the neck indicates completion of curing. However, it is preferable to move the onions, after topping, to a storage-curing room. Here they are piled to a depth not exceeding 15 feet and air is forced through the pile. It has been found satisfactory to circulate 1½ cubic feet of air per minute for each cubic foot of onions, using unheated outside air for the first 2 days, then air of 75° to 85° F (at the source of heat) with 60 percent relative humidity for 8 to 10 days and, finally, outside air to cool the onions before placing them in storage at 32° F. About 5 percent of the onion weight has to be evaporated, and completion of curing is indicated by a well-contracted neck and brittle skin. Overcuring will cause loss of skin. Excessive humidity or, perhaps, high temperatures will cause staining of the skin. The latter effect may also result from moisture condensation on the surface of the bulbs, as sometimes happens when outside air on a warm day is brought into contact with onions at a lower temperature, that is, when the onion temperature is below the dew point of the outside air.

Onions are classified by shape and color, the yellow globe types making up the major portion of commercial stocks. The varieties of this type that are most popular in Western Canada are Autumn Spice, Brown Beauty and Epoch (53). The appearance of each variety is influenced to a large extent by the method of curing. Air-curing within a building results in the most uniform color and condition of bulb. Curing to the correct level of moisture keeps the skin intact and gives it a bright appearance. (47, 53, 61, 115)

Parsnips

Temperature: 32° F.

Relative humidity: 95 percent.

Parsnips are usually handled like carrots and their storage life is 2 to 4 months at 32° F and high relative humidity. They are topped at harvest in the fall, and can be stored in bulk piles, but more often they are stored in bulk bins, boxes or other containers. The main storage problems with parsnips are a root discoloration for which there is no known cause or control, and their tendency to shrivel as a result of moisture loss. The latter can be controlled

by packing in damp sphagnum moss or other moisture-holding material. Parsnips have been successfully waxed for marketing but they are usually sold unwaxed. Parsnips will recover from light freezing but they should be protected from frost (69, 115).

Peas, Green

Temperature: 32° F.
Relative humidity: 95 percent.

This crop is similar to corn in that the most likely form of quality deterioration is through normal reactions involving the conversion of sugars to starch. If possible, peas should be stored in the pod and cooled immediately after harvest by icing or immersion in ice-water. Stored at 32° F, they may be held 1 to 2 weeks. At 40° F their storage life is about 3 to 4 days. Processing plants may have to store shelled, green peas. The storage life of peas in this form is much reduced but it can be extended by prompt cooling and washing to remove surface juice (115).

Peppers, Sweet

Temperature: 45° to 50° F.
Relative humidity: 85 to 90 percent.

Peppers have a storage life of 8 to 10 days at 45° to 50° F. Red color and decay develop rapidly at higher temperatures. Low-temperature injury takes the form of surface pitting and decay; about 5 days at 32° F will cause serious damage upon removal of the peppers to room temperature (115).

Potatoes, Early-crop

Temperature: see below.
Relative humidity: 85 to 90 percent.

Early-crop potatoes are harvested before reaching full maturity. They are used for immediate consumption and are unsuited to long storage. However, this crop can be kept for a few days or as long as several weeks if it is in sound condition. If intended for table use, potatoes can be stored at 50° F, but if they are held for processing, particularly for chipping, storage temperatures of 60° to 70° F are better. Whatever the temperature, the relative humidity should be 85 to 90 percent (115).

Potatoes, Late-crop

Temperature: see below.
Relative humidity: 85 to 90 percent.

Most potatoes are harvested at the "late-crop" stage. Time of harvest is determined by the maturity of the potatoes and the possibility of damage by low temperatures in the field. Maturity is difficult to define but the objective is to allow potatoes to reach maximum dry-matter content (high specific gravity) and to induce toughening or "setting" of the skin. These conditions are most nearly achieved when the vines have been dead for about 2 weeks. Usually the tops have to be killed either mechanically or by chemicals, or in

irrigated areas by water restriction. Top killing by chemical means is recommended when late blight infection is suspected (63).

Potatoes are often handled too roughly. This causes damage that results in several forms of loss, including loss of moisture, and increased susceptibility to disease and browning disorders. Injured and disease-infected potatoes should not be stored.

Curing of potatoes before placing them in storage is an extremely important operation. The objective is to improve their storage properties by making their skin firmer and tougher. This reduces subsequent moisture loss, increases resistance to disease, and aids in recovery from injury. The actual physiological processes involved are suberization and wound periderm formation. The first process is completed in about 2 days at 68° F whereas the second process is considerably slower (102). High temperatures and humidities are required for both processes. Curing is virtually stopped at temperatures of 46° F or lower. It requires a period of 10 to 14 days at temperatures of 56° to 60° F and very high (95 percent) relative humidity (63). However, if the presence of late blight is suspected the curing period may have to be shortened to avoid accelerated development of the disease.

The physiology of the potato is influenced markedly by temperature. Following curing, optimum storage temperatures are determined by the ultimate use of the crop, duration of storage and sprout inhibition treatment. Temperatures of 40° F and higher induce sprouting, whereas temperatures below 50° F induce sugar accumulation, and temperatures below 36° F may cause low-temperature injury (89). These factors dictate the following temperature recommendations:

Seed stock: 36° to 38° F; storage life: 7 to 8 months or longer.

Table stock: 45° to 50° F for short storage or until sprouting is imminent. The same temperatures can be used for long storage if sprout inhibitors are used, otherwise 39° F is required for long storage. Storage life is 4 to 9 months, depending on variety.

Stock for processing into potato chips: 50° F in combination with sprout inhibitors is best. If stored at 40° F, costly reconditioning is necessary to prevent browning.

Stock for processing into French fries: 40° to 45° F can be used because browning is not quite as critical as with chips.

Potatoes should be stored at a high relative humidity (85 to 90 percent) at all times. This is particularly true at temperatures of 45° F and higher, when shriveling is most likely to occur.

Sprout inhibitors perform an important function in storage by permitting storage at 50° F, thus avoiding the formation of sugars and the need for reconditioning. Maleic hydrazide (amine form) applied to the vines in the field, two weeks after full bloom, at the rate of 6½ pints of MH-amine in 80 to 120 gallons per acre, has been found very effective (44, 63). Isopropyl *N*-(3-chlorophenyl) carbamate (CIPC) can be applied satisfactorily in storage if all cuts and bruises on the potatoes are thoroughly healed before application (92). Gamma irradiation, at a level of 8,500 rads, using a cobalt-60 source, has been found effective (65). A possible increase in sugars as a result of irradiation

is a disadvantage (9), which, however, has been shown to be somewhat temporary (13). A method found highly satisfactory in the United Kingdom and elsewhere is the use of a nonyl alcohol (3,5,5-trimethyl-hexan-l-ol), which is applied directly to the stored potatoes by evaporating the alcohol into the ventilation system at a concentration of 1 ounce per 1000 cubic feet at an air flow rate of 5 cubic feet per minute per (long) ton of potatoes (8). (*Note:* Before any chemicals are employed the legal aspects of their use should be considered.)

Most potatoes are stored in common, air-cooled storage although refrigeration sometimes is used, mainly as an auxiliary source of cooling. Uniform air and temperature distribution are essential in maintaining good storage conditions. Otherwise, cold areas on the walls and ceiling of a storage room or in the stack itself may develop wet spots. If potatoes are piled in bins they should not be piled higher than 15 feet and the top of the pile should be kept level. A ridge at the top of a pile often provides conditions that lead to the formation of a wet spot. Although bags, boxes and other containers are still used, the trend is towards bulk boxes for economy in handling.

Light should be excluded from potato storages because it causes the production of chlorophyll (which gives the potatoes a green color) and also the formation of a bitter toxic compound, solanine.

The ventilation system and the insulation of storage buildings should provide adequate protection against low temperatures, particularly freezing during the winter. Conversely, admitting air that is at a higher temperature than the potatoes is likely to cause condensation (sweating). Ventilation should be sufficient to prevent the accumulation of carbon dioxide, which can cause increase in sugar content (42) or, possibly, blackheart under severe conditions (87).

The potato processing industry, and particularly potato chip manufacturers, are making special demands for potato storage quality. Dry-matter content, reducing-sugar content, and texture characteristics are being checked very closely. The proper selection of varieties, careful handling and adherence to proper storage management are the main factors contributing to high processing quality. If reducing sugars do accumulate, a reconditioning procedure consisting of exposure to 60° to 70° F for a week or longer permits them to be converted to starch or other compounds, or used in respiration. However, this procedure is often not effective for reasons not as yet completely understood. Soaking or washing the raw chips in water has been found effective (103). Varieties having a reputation for being suitable for reconditioning are Kennebec, Russet Rural and Rural New Yorker, but even these varieties fail to respond to reconditioning on rare occasions (12). Further information on potatoes is given in References 10, 63, 74, 87, 90, 109 and 115.

Pumpkins and Squash

Temperature: 44° to 50° F.
Relative humidity: 70 to 75 percent.

Pumpkins are a type of squash. The term pumpkin refers to the yellow globular types of squash. The storage life of pumpkins and squash depends

largely on their type and variety. In all cases, careful handling is important because injury to the skin is likely to lead to the development of rots in storage. Curing for 2 weeks at 80° to 85° F helps to heal minor injuries; this can be accomplished in the field, or in a storage with stoves or other sources of heat. For maximum storage life, squash should be allowed to reach full maturity before harvest and the stems should be completely removed at harvest to avoid any risk of damage in handling.

After curing, the temperature should be reduced to 44° to 50° F with 70 to 75 percent relative humidity. Varieties like Table Cream and Butternut will last for 2 months; Turban squash and Buttercup 3 months; and Hubbard (hard-shelled squash) for 6 months. For best storage results, squash should be stored on slatted shelves one layer deep without touching each other. Pumpkins generally do not store as well as the other types of squash and are seldom held longer than a few weeks.

Summer squash (*Cucurbita pepo*) is harvested before reaching full maturity. Its storage life is short, not exceeding 2 weeks. Summer squash is usually stored at 32° F and a relative humidity of 85 to 90 percent. (93, 115)

Radishes

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Spring radishes are usually marketed in the bunched form with tops retained. There is a trend, however, towards marketing topped spring radishes in plastic bags. Spring radishes have a storage life of about 14 days when held at 32° F and high relative humidity. Their fresh appearance and marketability are improved by hydrocooling and ample icing before and during transit. Winter or large radishes will keep in good condition for 2 to 4 months under the storage conditions recommended for spring radishes. (115)

Rhubarb

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Rhubarb stalks, if fresh and in good condition, may be stored for 2 to 3 weeks. Bunches should be packed in crates, which are stacked to allow ample air circulation on all sides; otherwise there is a danger of heating and mold growth (115).

Rutabagas or Turnips

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

The Laurentian variety is most commonly grown and appears to be the most satisfactory for storage and the market. It can be kept in good condition up to 6 months at 32° F and 90 to 95 percent relative humidity. There is a general tendency to disregard the need for careful handling during harvest operations. Those who practise careful handling, however, find that it pays off in the form of reduced rot and other injury during the storage period.

The use of maleic hydrazide has been found to be effective in reducing sprouting when the crop is stored under less than optimum conditions. (*Important:* Before using any chemicals refer to the legal regulations that apply to their use in your area.) The rutabaga is usually stored in bulk, but bulk-bins are preferred.

This crop responds well to waxing. If properly waxed, rutabagas lose less moisture and are more attractive. This waxing procedure, used after storage, has contributed largely to the high international reputation of Canadian rutabagas. (33, 52, 64)

Salsify

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Salsify has the same storage requirements as topped carrots. The roots are not injured by light freezing but should be handled carefully while frozen. Under the conditions specified, they should keep for 2 to 4 months (115).

Spinach

Temperature: 32° F.
Relative humidity: 90 to 95 percent.

Spinach is usually stored for only short periods. It should keep fairly well for 10 to 14 days after being cut. If crushed ice is used in the packages this period can be extended somewhat (115).

Sweet Potatoes

Temperature: 55° to 60° F.
Relative humidity: 85 to 90 percent.

Only recently has there been much interest in growing this crop in Canada. It requires long periods of warm weather for growth and also high temperatures for storage. Low-temperature injury occurs in storage at temperatures below 50° F; this results in pitting, particularly if the sweet potatoes have not been cured, and in increased decay and discoloration, either before or after cooking.

At harvest, sweet potatoes should be fully mature and free from injury. For satisfactory storage, they should be cured for 10 days at 85° F with 90 percent or higher relative humidity. Heating equipment and the addition of moisture are usually required for this operation. After curing, the temperature is reduced to 55° to 60° F with 85 to 90 percent relative humidity. Under these conditions sweet potatoes should keep for 4 to 6 months (115).

Tomatoes

Temperature: ripe 50° F; partially ripe 55° to 60° F.
Relative humidity: 85 to 90 percent.

Tomatoes are usually harvested while green (mature-green) or partially colored. The objective in storage after harvest is to control the rate of ripening. At 50° F the rate of color change as well as the development of such effects

as uneven coloring, pitting, breakdown and poor flavors are much reduced (107, 114). This temperature effect is rather complex; under some circumstances no apparent damage occurs during short exposures to lower temperatures. (114)

A temperature of 55° F is recommended for slow ripening. At this temperature most varieties keep in good condition for 2 to 6 weeks and change color very slowly. At 60° F the rate of color change increases quite sharply (94), and above 70° F the rate of maturation and other changes is increased. Tomatoes held at 65° F change color rapidly without excessive softening. Temperatures of 70° F or higher induce rapid ripening and bring about changes in color, softening and flavor.

When tomatoes are fully ripe, the holding time can be increased by reducing the temperature to 50° F. Some experiments have shown that ripe tomatoes can be held satisfactorily at 32° to 38° F. It has been shown, however, that some softening may occur at 35° F (37). Thus, it is generally considered hazardous to hold ripe tomatoes in storage for more than a few days.

Ethylene has been used to a very limited extent to increase rate of ripening and particularly to bring about color changes. However, it has not been proved to be consistently effective for these purposes (22). For further information on tomatoes, see References 86, 114, and 115.

APPENDIX

Sample Calculation of Refrigeration Load

To illustrate how to calculate refrigeration loads, an apple storage is used here as an example of a typical storage unit. The storage is assumed to have dimensions of about 35 × 40 × 18 feet, to have a capacity of approximately 25,000 cubic feet, and be suitable for storing 9,000 bushels of apples. It is also assumed that the storage is of frame construction, having 4-inch batt-type insulation between studs in the wall, 4-inch board-type insulation in the ceiling, and 4 inches of peripheral insulation of the foundation wall; that the storage floor is concrete supported by loose fill (gravel or stone) on the ground; and that there is an air space or loft above the storage under a trussed rafter roof. (This does not constitute a recommended design. For recommended designs consult Reference 11.) Furthermore, it is assumed that the storage is operated at 32° F with an outside temperature of 70° F.

The three main components of refrigeration load — heat leakage, field heat and heat of respiration — are each calculated in turn as follows:

Heat leakage, for purposes of calculating refrigeration loads, means heat leaking into the storage room from the outside. The higher the temperature differential between the inside and the outside of a storage room, the greater will be the amount of heat leaking inwards. Heat leakage is controlled mainly by insulating materials used in the building structure. All the other structural components such as plywood, sheathing, roofing materials and supporting members contribute to the overall insulation of the building. However, these contributions rarely exceed 15 percent of the total insulating effect and are likely to be 10 percent or less. Thus, in calculating heat load, only the insulating material will be considered here. Any extra insulation above this will be a useful safety allowance.

Most recommended insulating materials (11) have a conductivity factor (k) of 0.26 to 0.30. This figure indicates the number of Btu per hour passing through one square foot of the material by conduction when the temperature difference between the inner and outer surfaces of the material is 1° F. Wood has a k factor of about 1, concrete 6, and brick 5, which means that about 3 times, 20 times, and 15 times the thickness respectively of these materials are required to provide the same insulation effect as good insulating materials. These values vary somewhat, depending on such factors as density and moisture content. (74)

The amount of heat leakage depends on: temperature differential, area of exposed surface, thickness of insulation, and the conductivity or k factor of the insulation. In our example the temperature difference is 38° F (70° - 32°), the area of the wall surface is 2,700 square feet (150 × 18 feet), the insulation

thickness is 4 inches, and the k factor is 0.27. Thus, the total heat leakage through the walls is:

$$\frac{38 \times 2{,}700 \times 0.27}{4} = 6{,}925 \text{ Btu per hour.}$$

Similarly, for the ceiling, the area is 1,400 square feet, the insulation thickness is 4 inches, the k factor is 0.27, and the temperature differential is 38° F. Therefore, the total heat leakage through the ceiling is:

$$\frac{38 \times 1{,}400 \times 0.27}{4} = 3{,}591 \text{ Btu per hour.}$$

Heat leakage through the floor is somewhat more difficult to calculate accurately because of the uncertainty of the underground temperature and insulating properties of underground materials. However, heat leakage through the aboveground portion of the peripheral insulation would be the same as for the wall area, with the possible exception of this insulation having a slightly higher k factor. If the k factor is assumed to be 0.30, the heat transfer through this region would be:

$$\frac{38 \times 150 \times 0.30}{4} = 427.5 \text{ Btu per hour.}$$

The insulated area below ground would have the same characteristics as the aboveground portion except that there would be a lower outside temperature. If the air temperature were 70° F, the mean soil temperature might be 60° F. With this assumption the heat leakage would be:

$$\frac{28 \times 150 \times 0.30}{4} = 315 \text{ Btu per hour.}$$

The above calculation does not allow for the insulating effect of soil and fill under the storage floor area. Thus, the heat leakage would be somewhat less than indicated above but the difference would possibly be offset by heat leakage through the foundation wall below the insulation. For practical purposes, therefore, the total heat leakage for the storage room in Btu per hour would be:

Wall—above storage floor		6,925
Ceiling area		3,591
Floor area through foundation		
wall above ground	427.5	
wall below ground	315.0	
Total for floor		742.5
Total heat leakage		11,258.5

Thus, the refrigeration load to handle heat leakage would be:

$$\frac{11{,}258.5}{12{,}000} = 0.9 \text{ tons per hour.}$$

Field heat is generally the greatest portion of the total refrigeration load. It represents the heat that has to be removed from produce and containers in order to reduce their temperature to the desired holding temperature. The calculation of field heat is relatively straightforward:

(total weight) × (specific heat of the produce or container) × (the required reduction in temperature) = (total field heat)

Assuming that, at peak operating conditions, 1000 bushels or 22½ tons (45,000 lb) of apples per day are to be cooled from 70° to 32° F and their specific heat is 0.87 Btu per pound, the maximum refrigeration load would be:

$$\begin{aligned}45{,}000 \times 0.87 \times 38 &= 1{,}487{,}700 \text{ Btu per day}\\ &= 61{,}988 \text{ Btu per hour}\\ &= 5.2 \text{ tons of refrigeration.}\end{aligned}$$

The field heat calculation for the containers, which we may assume to be orchard boxes of one bushel capacity, weighing 10 pounds and having a specific heat of 0.42* Btu per pound, would be 1000 × 10 × 0.42 × 38 = 159,600 Btu per day, or 6,650 Btu per hour. This represents 0.6 tons of refrigeration.

Thus, under these circumstances, the total field heat load is 5.2 + 0.6 = 5.8 tons of refrigeration.

Heat of respiration is an extremely variable portion of the refrigeration load. The rate of respiration varies with the kind and variety of produce, the storage temperature, the conditions under which the produce was grown, and its stage of maturity at harvest. Table 6 gives approximate values for the rate of evolution of heat for various crops at 32°, 40° and 60° F.

*This value is for a dry box, if it has absorbed any moisture this value will increase.

Table 6. — Approximate Rates of Evolution of Heat by Certain Fresh Fruits and Vegetables When Stored at the Temperature Indicated(a)

Commodity	Rate of evolution of heat (Btu per ton per 24 hours) 32°F(b)	40°F(b)	60°F(b)
Apples	900	1,600	7,000
Asparagus	20,000	———	———
Beans			
Green or snap	5,000	10,000	40,000
Lima	2,800	5,000	25,000
Beets, topped	2,700	4,100	7,200
Blueberries	2,000	3,500	10,000
Broccoli, sprouting	7,500	17,000	50,000
Brussels sprouts	8,000	11,000	27,000
Cabbage	1,200	1,700	4,100
Carrots, topped	2,100	3,500	8,100
Cauliflower	2,000	4,500	10,000

Commodity	Rate of evolution of heat (Btu per ton per 24 hours) 32°F(b)	40°F(b)	60°F(b)
Celery	1,600	2,400	8,200
Cherries	1,700	2,500	12,000
Corn, sweet	9,000	12,000	38,000
Cranberries	700	1,000	3,000
Cucumbers	1,700	2,500	6,000
Grapes, American	600	1,200	3,500
Lettuce, head	2,300	2,700	8,000
Lettuce, leaf	4,500	6,400	14,000
Melons, cantaloupes	1,300	2,000	8,500
Mushrooms	6,200	12,000	46,000
Onions	1,000	800	2,400
Oranges(c)	800	1,500	5,000
Peaches	1,300	2,000	9,000
Pears	900	1,700	10,000
Peas, green	8,400	16,000	44,000
Peppers, sweet	2,700	4,700	8,500
Plums	700	1,500	2,800
Potatoes, immature	800	2,600	6,000
Potatoes, mature	700	1,800	2,600
Raspberries	5,000	8,000	22,000
Spinach	5,000	11,000	38,000
Strawberries	3,800	6,800	20,000
Sweet Potatoes	2,400	3,400	6,300
Tomatoes, mature green	600	1,100	6,200
Tomatoes, ripe	1,000	1,300	5,600
Turnips (Rutabaga)	1,900	2,200	5,300

(a) Data in this table have been derived from many sources. See References 3 and 115 in particular.

(b) Available data were adjusted to these temperatures by interpolation or extrapolation, when not available for the specific temperature.

(c) Values for other citrus fruits are similar to those for oranges.

Heat of respiration is an important part of the total heat load in storages; it may also be the cause of local heating and rapid produce deterioration if air movement is inadequate. This can occur wherever a fruit or vegetable itself or a package or a method of storage prevents transfer of heat of respiration from produce. Thus, sweet corn, or other vegetables in too large a pile, or even boxed apples packed too tightly in storage, pose heat exchange problems.

Temperature greatly affects the rate of respiration and must be given special attention in any calculation of the heat produced in respiration. The refrigeration load due to the heat of respiration changes when a storage is being filled and cooled. In our example, if the storage is loaded with apples in nine days at the rate of a 1000 bushels (22½ tons) per day, if the apples have an initial temperature of 70° F, and if they are cooled to 32° F in eight days

(30° F in 10 days), the respiration heat load will be 411,000 Btu on the ninth day, as shown in Table 7. This represents 16,800 Btu per hour or 1.4 tons of refrigeration.

Table 7. — Heat of Respiration of Apples

(Data are typical for a loading rate of 1,000 bushels daily with an initial temperature of 70°F cooled to 32°F in 8 days, in a storage room of 9,000 bushels capacity.)

Days after start of loading	Mean Temp. (°F)	Heat produced on successive days of loading (Thousands of Btu per 1,000 bushels of apples per day)									Heat first day after loading (Btu)
		1	2	3	4	5	6	7	8	9	
1	62.5	168	168	168	168	168	168	168	168	168	56
2	48.3		56	56	56	56	56	56	56	56	43
3	43.5			43	43	43	43	43	43	43	36
4	39.3				36	36	36	36	36	36	25
5	36.2					25	25	25	25	25	22
6	34.4						22	22	22	22	21
7	33.1							21	21	21	20
8	32.0								20	20	20
9	32.0(a)									20	20
Totals		168	224	267	303	328	350	371	391	411	263

(a) If temperature were reduced to 30°F this point would be reached in about 10 days with cooling at the same rate, and would be 31°F on day 9 with a respiration heat of 19,000 Btu.

In an actual cooling operation, the mean temperature for each successive day would decrease, as noted in this table. In our example, the second day brought about a decrease in temperature from 62.5° F to 48.3° F with a reduction in daily heat production from 168,000 to 56,000 Btu for the 1000 bushels of apples. This represents a reduction of 70 percent of the heat of respiration and emphasizes the importance of initial rapid cooling.

In making a practical assessment of the quantity of heat produced by respiration it should be remembered that the above figures are calculated from averages. It is quite possible that the quantities produced by some apples may exceed the average by 60 to 75 percent, but it is not likely that this will occur consistently throughout a whole loading period. However, these calculations should be modified if apples are placed in storage at a different temperature. Thus, if apples were stored at 80° F instead of 70° F the respiration heat load would be increased by 30 percent.

The data in Table 7 represent an eight-day cooling rate from 70° to 32° F. It is quite feasible with modern equipment to cool apples or other produce in three or four days. With a four-day cooling rate, the total heat of respiration would be reduced from 411,000 Btu to 270,000 Btu per day, representing a reduction of about 35 percent. Similarly, if the cooling period were longer

than eight days, the refrigeration load would be increased. This occurs when the refrigeration equipment is inadequate and the cooling of each load is slower; in an extreme situation there might be no reduction in produce temperature.

Total refrigeration load — The important calculation from the storage operator's standpoint is the total refrigeration load. The main components of this calculation have been illustrated with our example of an apple storage having 9,000-bushel capacity insulated in a "standard" manner and loaded at a rate of 1000 bushels per day with fruit having an average temperature of 70° F, the average outside temperature being the same.

In summary, the calculations show:

Heat Leakage:	0.9 tons of refrigeration
Field Heat:	5.8 tons of refrigeration
Respiration:	1.4 tons of refrigeration
Total:	8.1 tons of refrigeration

This represents refrigeration requirements without any surplus. It is customary to add at least 10 percent for exigencies. In our example this would bring the requirement to 10 tons of refrigeration. A larger storage, with a proportionate increase in loading time, would increase the ratio of heat leakage to other heat sources. Field heat, always the largest load component, is proportional to loading rate.

REFERENCES

1. Allen, F. W. The harvesting and handling of fall and winter pears. Bull. Calif. agric. Exp. Stn. 533. 1932. 46 p.
2. ...., W. R. Redit, and W. T. Pentzer. Apples, pears and grapes. *In* Air Condit. Refrigng Data Book, Applications Vol. 5th ed. 1955. chap. 19.
3. American Society of Heating, Refrigerating, and Air Conditioning Engineers Inc. Commodity storage requirements. *In* ASHRAE Guide and Data Book; Applications. New York. 1962. p. 483-494.
4. Appleman, C. O., and J. M. Arthur. Carbohydrate metabolism in green sweet corn during storage at different temperatures. J. agric. Res. 17: 137-152. 1919.
5. Atkinson, F. E., and D. V. Fisher. Harvesting, storing and ripening Bartlett pears for canning. Can. Food Ind. 25(4): 37-38. 1953.
6. Barker, J., and T. N. Morris. The storage of asparagus. Rep. Food Invest. Bd. 1936. p. 172-173.
7. Brooks, C., J. S. Cooley, and D. F. Fisher. Diseases of apples in storage. Farmers' Bull. U.S. Dep. Agric. 1160. 1935. 20 p.
8. Burton, W. G. Suppression of potato sprouting in buildings. Agriculture, Lond. 65: 299-305. 1958.
9. ...., T. Horne, and D. B. Powell. The effect of gamma irradiation upon the sugar content of potatoes. Eur. Potato J. 27: 105-116. 1959.
10. Campbell, John C., Ed. Potato Handb. 7. 1962. 80 p.
11. Canadian Farm Buildings Plan Service. Catalogue of plans — fruit and vegetable buildings and equipment. Ottawa, Queen's Printer, 1964. 44 p.
12. Chapman, H. W. Post harvest physiology of potatoes for processing. Potato Handb. 7: 48-52. 1962.
13. Cloutier, J. A. R., Marilyn G. Clay, Jane M. Manson, and L. E. Johnson. Effect of storage on the carbohydrate content of two varieties of potatoes grown in Canada and treated with gamma radiation. Food Res. 24(6): 659-664. 1959.
14. Cook, Harold T., and W. T. Pentzer. Supplements to refrigeration. *In* Air Condit. Refrigng Data Bk; Applications Vol. 5th ed. 1955. chap. 25.
15. Dewey, D. H., W. E. Ballinger, and I. J. Pflug. Progress report on the controlled-atmosphere storage of Jonathan apples. Q. Bull. Mich. State Univ. agric. Exp. Stn 39: 691-700. 1957.
16. Eaves, C. A. The storage and shipment of fruit in modified-atmosphere bulk bins. J. hort. Sci. 38: 214-221. 1963.
17. .... A dry scrubber for CA apple storages. Trans. Am. Soc. agric. Engrs. 2(1): 127-128. 1959.
18. ...., and H. Hill. Functional disorders of apples. Dep. Agric. Can. Pub. 694. (Tech. Bull. Dep. Agric. Can. 28). 1940.
19. ...., F. R. Forsyth, J. S. Leefe, and C. L. Lockhart. Effect of varying concentrations of oxygen with and without CO_2 on senescent changes in stored McIntosh apples grown under two levels of nitrogen fertilization. Can. J. Plant Sci. 44: 458-465. 1964.
20. Edney, K. L. Some factors affecting the rotting of stored apples by *Gloeosporium* spp. Ann. appl. Biol. 53: 119-127. 1964.
21. Fidler, J. C. Scald and weather. Food Sci. Abstr. 28(6): 545-554. 1957.
22. ...., and J. R. H. Nash-Wortham. Ripening of tomatoes. J. hort. Sci. 25: 183-189. 1950.
23. Fisher, D. F., C. P. Hurley, and C. Brooks. The influence of temperature on the development of water core. Proc. Am. Soc. hort. Sci. 27: 276-280. 1930.
24. Fisher, D. V. A three year study of maturity indices for harvesting Italian prunes. Proc. Am. Soc. hort. Sci. 37: 183-186. 1939.
25. .... Mealiness and quality of Delicious apples as affected by growing conditions. Scient. Agric. 23: 569-588. 1943.
26. ...., and J. E. Britton. Maturity and storage studies with peaches. Scient. Agric. 21: 1-17. 1940.

27. ...., and J. E. Britton. Maturity studies with sweet cherries. Scient. Agric. 29: 497-503. 1940.

28. ...., J. E. Britton, and H. J. O'Reilly. Peach harvesting and storage investigations. Scient. Agric. 24: 1-15. 1943.

29. ...., R. C. Palmer, and S. W. Porritt. Pear harvesting and storage in British Columbia. Dep. Agric. Can. Pub. 895. 1953. 22 p.

30. ...., and S. W. Porritt. Apple harvesting and storage in British Columbia. Dep. Agric. Can. Pub. 724. 1951. 47 p.

31. ...., and S. W. Porritt. Some recent studies in late harvesting and delayed cold storage of Bartlett pears. Proc. Am. Soc. hort. Sci. 65: 223-230. 1955.

32. ...., and S. W. Porritt. Influence of degree of maturity of harvest and length of delay between orchard and storage upon keeping life of Bartlett pears at 32°F. 9th Int. Congr. Refrig. Inds Vol. 2, 4.217-4.223. 1955.

33. Franklin, E. W. The waxing of turnips for the retail market. Dep. Agric. Can. Pub. 1120. 1961. 4 p.

34. Gerhardt, F., and H. English. Ripening of the Italian prune as related to maturity and storage. Proc. Am. Soc. hort. Sci. 46: 205-209. 1945.

35. ...., and A. Lloyd Ryall. The storage of sweet cherries as influenced by carbon dioxide and volatile fungicides. Tech. Bull. U.S. Dep. Agric. 631. 1939. 20 p.

36. Gray, Harold E. Farm refrigerated storages. Cornell Ext. Bull. 786. 1950. 48 p.

37. Hall, C. B. The effect of low storage temperatures on the color carotinoid pigments, shelf-life and firmness of ripened tomatoes. Proc. Am. Soc. hort. Sci. 78: 480-487. 1961.

38. Haller, Mark H. Fruit pressure testers and their practical application. Washington, D.C., Circ. U.S. Dep. Agric. 627. 1941. 22 p.

39. Hardenburg, R. E., and R. E. Anderson. Chemical control of scald on apples grown in eastern United States. Mktg Res. Rep. U.S. Dep. Agric. 538. 1962. 48 p.

40. Harvey, John M., and W. T. Pentzer. Market diseases of grapes and other small fruits. Agric. Handb. Mktg Serv. U.S. 189. 1960. 37 p.

41. Heald, F. D., and G. D. Ruehle. Fungal wastage. Bull. Wash. agric. Exp. Stn. 253. 1931. 48 p.

42. Heinze, P. N., and others. Storage and transportation of potatoes. Potato Handb. 9: 30-34. 1964.

43. Hill, H., and others. The relation of foliage analysis to keeping quality of McIntosh and Spy varieties of apples. Sci. Agric. 30: 518-534. 1950.

44. Hoffman, I., and R. B. Carson. Determination and distribution of maleic hydrazide in vegetables and fruit. J. Ass. off. agric. Chem. 45: 788-789. 1962.

45. Hudek, E. P. Storage requirements of potatoes. Proc. Can. Potato Ind. Conf. (processed) 7. 1964. p. 77-83.

46. Huelson, Walter A. Sweet corn. New York, Interscience Publishers Inc., 1954. 409 p. (Economic Crops Vol. 4)

47. Isenberg, F. M., and J. K. Ang. Northern grown onions — curing, storing and inhibiting sprouting. Cornell Ext. Bull. 1116: 1963. 15 p.

48. Jones, H. H., J. G. Desmarais, and K. E. Winfield. How efficient are fungicidal paints? Can. Paint Varn. Mag. 30(5): 30-35, 52-54. 1956.

49. Kasmire, R. F., and A. F. Van Maren. Facts on hydrocooling sweet corn. Univ. Calif. Agric. Ext. Serv. AXT-12 (processed), 1961. 9 p.

50. Kidd, Franklin, and Cyril West. The refrigerated gas-storage of apples. Food Invest. Leafl. 6. 1936. 12 p.

51. ...., and Cyril West. The refrigerated gas-storage of pears. Food Invest. Leafl. 12. 1949. 12 p.

52. King, E. M. Swede turnip culture. Hort. Circ. B.C. 85. 1959. 7 p.

53. .... Storage onions. Hort. Circ. B.C. 90. 1961. 6 p.

54. .... Asparagus production in British Columbia. Hort. Circ. B.C. 96. 1962. 8 p.

55. Lentz, C. P., and E. A. Rooke. Rates of moisture loss of apples under refrigerated storage conditions. Food Technol., Champaign 18(8): 119-121. 1964.

56. ...., and E. A. Rooke. Use of the jacketed room system for cool storage. Food Technol. Champaign 11(5): 257-259. 1957.

57. Lott, Richard. Some spectral curves of maturing apples. Proc. Am. Soc. hort. Sci. 43: 59-62. 1943.

58. Mattus, G. E., and F. M. Hassen. Peach decay control with hot water treatments. Virginia Fruit 51(7): 35-36. July 1963.

59. Miller, Erston V., and Charles Brooks.

Effect of carbon dioxide content of storage atmosphere on carbohydrate transformation in certain fruits and vegetables. J. agric. Res. 453: 449-459. 1932.
60. McMechan, A. D., and D. V. Fisher. The bulk bin method of handling of fruit. Can. J. Plant Sci. 38: 440-444. 1958.
61. Nuttall, V. W., L. H. Lyall, and K. F. MacQueen. Some effects of gamma radiation on stored onions. Can. J. Plant Sci. 41: 805-813. 1961.
62. Ogle, W. H., and E. P. Christopher. The influence of maturity temperature and duration of storage on quality of cantaloupes. Proc. Am. Soc. hort. Sci. 70: 319-324. 1957.
63. Ontario Agricultural College. Potato production in Ontario. Dep. Agric. Ont. Pub. 534. 1960. 64 p.
64. Ontario Agricultural College. Table turnips (rutabagas). Dep. Agric. Ont. Pub. 502. 1960. 14 p.
65. Parks, N. M. Gamma irradiation of potatoes; storage tests. *In* Gamma Irradiation in Canada. Ottawa, Atomic Energy of Canada Ltd., 1960. p. 18-23.
66. Patterson, Max E., and J. Milton Workman. The influence of O_2 and CO_2 on the development of apple scald. Proc. Am. Soc. hort. Sci. 80: 130-135. 1962.
67. Pentzer, W. T., and F. W. Allen. Ripening and breakdown of plums as influenced by storage temperature. Proc. Am. Soc. hort. Sci. 44: 148-156. 1944.
68. ...., R. L. Perry, G. C. Hanna, J. S. Wiant, and C. E. Asbury. Precooling and shipping California asparagus. Bull. Calif. agric. Exp. Stn. 600. 1936. 45 p.
69. Phillips, W. R. Construction and operation of a home storage for fruits and vegetables. Dep. Agric. Can. Pub. 743 rev. 1957. 15 p.
70. .... Gamma irradiation of apples. Can. Food Ind. 34(8): 38-40. 1963.
71. ...., F. S. Browne, and P. A. Poapst. Precooling celery. Can. Refrig. J. 18(1): 19-23. 1952.
72. ...., C. P. Lentz, and E. A. Rooke. The use of the jacketed room system for the storage of apples. Can. Refrig. Air Condit. 27(12): 20-23. 1961.
73. ...., K. F. MacQueen, and P. A. Poapst. The effect of irradiation on the development of storage disorders of apples. 10 Int. Congr. Refrig. Inds 3: 176-180. 1959.
74. ...., and N. M. Parks. Potato storage. Dep. Agric. Can. Pub. 882. 1957. 18 p.
75. ...., and P. A. Poapst. Storage of apples. Dep. Agric. Can. Pub. 776 rev. 1952. 43 p. and supplement: Controlled atmosphere storage of apples. 1959. 17 p.
76. ...., and P. A. Poapst. Starch test guide for harvesting McIntosh apples. Extract from Dep. Agric. Can. Pub. 776 (processed) rev. 1960. 2 p.
77. ...., P. A. Poapst, and B. J. Rheaume. The effect of temperature near 32° F on the storage behaviour of McIntosh apples. Proc. Am. Soc. hort. Sci. 65: 214-222. 1955.
78. ...., and P. A. Poapst. Low temperature research. *In* Prog. Rep. hort. Div. exp. Farms Serv. Can. 1944-58. 1961. p. 79-97.
79. Platenius, H. Wax emulsions for vegetables. Bull. Cornell Univ. agric. Exp. Stn. 723. 1939. 43 p.
80. Poapst, P. A., G. M. Ward, and W. R. Phillips. Maturation of McIntosh apples in relation to starch loss and abscission. Can. J. Plant Sci. 39: 257-263. 1959.
81. Porritt, S. W. The effect of temperature on post harvest physiology and storage life of pears. Can. J. Plant Sci. 44: 568-579. 1964.
82. .... Effect of cooling rate on storage life of pears. Can. J. Plant. Sci. 45: 90-97. 1965.
83. ...., A. D. McMechan, and K. Williams. Note on a floatation method for segregation of water core apples. Can. J. Plant Sci. 43: 600-602. 1963.
84. Ramsey, Glen B., R. A. Friedman, and M. A. Smith. Market diseases of beets, chicory, endive, escarole, globe artichokes, lettuce, rhubarb, spinach and sweet pota. toes. Agric. Handb. Mktg Serv. U. S. 155-1959. 42 p.
85. ...., and M. A. Smith. Market diseases of cabbage, cauliflower, melons and related crops. Agric. Handb. Mktg Serv. U. S. 184. 1961. 49 p.
86. ...., James S. Wiant, and Leacy P. McColloch. Market diseases of tomatoes, peppers and eggplants. Agric. Handb. U.S. Dep. Agric. 28. 1952. 43 p.
87. ...., James S. Wiant, and Marion B. Smith. Market diseases of fruits and vegetables — potatoes. Misc. Publs U.S. Dep. Agric. 98. rev. 1949. 60 p.
88. Redit, W. H., and A. A. Hamer. Protection of rail shipments of fruits and vege-

tables. Agric. Handb. Mktg Serv. U.S. 195. 1961. 108 p.
89. Richardson, L. T., and W. R. Phillips. Low temperature breakdown of potatoes in storage. Scient. Agric. 29: 149-166. 1949.
90. Rose, Dean H. Handling, storage, transportation, and utilization of potatoes. U.S. Dep. Agric. Bibliographical Bull. 11. 1949. 163 p.
91. ...., L. P. McColloch, and D. F. Fisher. Market diseases of fruits and vegetables — apples, pears and quinces. Misc. Publs U.S. Dep. Agric. 168. 1951. 72 p.
92. Sawyer, R. L. Chemical sprout inhibitors. *In* Potato Handb. 7: 5-9. 1962.
93. Schales, Franklin D., and F. M. Isenberg. The effect of curing and storage on chemical composition and taste acceptability of winter squash. Proc. Am. Soc. hort. Sci. 83: 667-674. 1963.
94. Scott, L. E., and J. E. Hawes. Storage of vine-ripened tomatoes. Proc. Am. Soc. hort. Sci. 52: 393-398. 1948.
95. Smith, W. Hugh. The commercial storage of vegetables. Food Invest. Leafl. 15. 1952. 8 p.
96. Smock, R. M. Controlled atmosphere storage of apples. Cornell Ext. Bull. 759. rev. 1958. 36 p.
97. .... The storage of apples. Cornell Ext. Bull. 440. 1940. 38 p.
98. .... A new method for scald control. Am. Fruit Grow. Mag. 75(11): 20. 1955.
99. ...., and A. M. Neubert. Apples and apple products. New York, Interscience Publishers, Inc. 1950. 486 p. (Economic Crops Vol. 2)
100. Southwick, F. W., and Melvin Hurd. Harvesting, handling and packing apples. Cornell Ext. Bull. 750. 1948. 37 p.
101. Strachan, C. C. Quality of canned peaches affected by maturity, ripening and storage. Can. Food Ind. 27(7): 20-21, 23. 1956.
102. Toko, Harvey V., and Edward F. Johnston. Effects of storage on post harvest physiology of potatoes used as table stock and seed. Potato Handb. 7: 10-17. 1962.
103. Townsley, P. M. Eliminate conditioning period in chip manufacture. Can. Food Ind. 23(6): 26-29. 1952.
104. Truscott, J. H. L. Storage root rot of celery. *In* Rep. hort. Exp. Stn Prod. Lab. Vineland 1953-1954. (Toronto, 1954.) p. 122-127.
105. .... Peach cooling in the Niagara area. *In* Rep. hort. Exp. Stn Prod. Lab. Vineland 1955-1956. (Toronto, 1956.) p. 106-111.
106. .... Bartlett and Bosc pears in controlled atmosphere (gas) storage. *In* Rep. hort. Exp. Stn Prod. Lab. Vineland 1959-1960. (Toronto 1960.) p. 113-114.
107. ...., and Lloyd Brubacher. Tomato storage. *In* Rep. hort. Exp. Stn Prod. Lab. Vineland 1963. (Toronto, 1963.) p. 61-67.
108. Thompson, Ross C. Asparagus culture. Farmers' Bull. U.S. Dep. Agric. 1646 rev. 1954. 22 p.
109. Twiss, P.T.G. Quality as influenced by harvesting and storage. *In* The Growth of the potato. Edited by J. D. Ivins and F. L. Milthorpe. London, Butterworths, 1963. p. 281-291.
110. Uota, M. Temperature studies on the development of anthocyanin in McIntosh apples. Proc. Am. Soc. hort. Sci. 59: 231-237. 1952.
111. Weir, F. J. Home storage of vegetables. Manitoba Dep. Agric. Pub. 297. 1957. 8 p.
112. Whiteman, T. M. Freezing points of fruits, vegetables, and florist stocks. Mktg Res. Rep. U.S. Dep. Agric. 196. 1957. 32 p.
113. Wright, R. C., and others. Commodity storage requirements. *In* Air Condit. Refrigng Data Book; Applications Vol. 5th ed. 1955. chap. 18.
114. ...., and others. Effect of various temperatures on the storage and ripening of tomatoes. Tech. Bull. U.S. Dep. Agric. 268. 1931. 35 p.
115. ...., Dean H. Rose, and T. M. Whiteman. The commercial storage of fruits, vegetables and florist and nursery stocks. Agric. Handb. U.S. Dep. Agric. 66. 1963. 77 p.
116. Yamaguchi, M., Harlan K. Pratt, and Leonard L. Morris. Effect of storage temperatures on keeping quality of onion bulbs and on subsequent darkening of dehydrated flakes. Proc. Am. Soc. hort. Sci. 69: 421-426. 1957.

First Printed 1967

Reprinted 1969

Copies of this publication may be obtained from:

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CANADA DEPARTMENT OF AGRICULTURE
OTTAWA

ROGER DUHAMEL, F.R.S.C., QUEEN'S PRINTER AND CONTROLLER OF STATIONERY, OTTAWA, 1967

10M-34579-1:69 CAT.NO.A53-1260